A QUALITATIVE ASSESSMENT OF BIOMIMETIC AND VERNACULAR APPROACHES TO DESIGN FOR EXTREMELY HOT ENVIRONMENTS OF THE GCC COUNTRIES

A Dissertation

by

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ABSTRACT

The impacts of global climate change on the designed and built environment have accelerated in the twenty-first century, leading contemporary architects to reconsider conventional building practices. For many centuries, humans in different parts of the world have viewed themselves as separate from nature and the natural environment as separate from the built environment. This attitude has driven design and construction practices contributing to environmental degradation and global climate change. As a result, architects recognize the importance of devising new approaches to design and construction to mitigate the adverse effects of the built environment on the natural environment. Such changes require a shift from an anthropocentric view to an eco-centric view. This dissertation investigates whether existing and new projects in the Middle East, especially GCC countries, are following the recommended strategies for hot climate and whether architects and designers can harness the principles of biophilia, biomimicry, and indigenous building practices to design buildings that protect occupants from increasingly extreme temperatures while mitigating the contributions of the designed and built environment to environmental degradation and global climate change.

DEDICATION

To Mamte, whose smile reminds me of the morning.

Nada and Duaa,

for their long-distance sisterhood.

And to my husband, Abdullah,

for keeping his promise every time he told me that

“Everything’s going to be okay”

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NOMENCLATURE

GCC	Cooperation Council for the Arab States of the Gulf. (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates).
Biomimicry	Learning from and then emulating nature's forms, processes, and ecosystems to create more sustainable designs.
Anthropocene	The current geological age, viewed as the period during which human activity has been the dominant influence on climate and the environment.
Indigenous people	are distinct social and cultural groups that share collective ancestral ties to the lands and natural resources where they live, occupy or from which they have been displaced.
Biophilia	The biophilia hypothesis suggests that humans possess an innate tendency to seek connections with nature and other forms of life.
Vernacular Architecture	An architectural style that is designed based on local needs, availability of construction materials, and reflecting local traditions.
Extreme temperature	Above human tolerance, which is 31°C wet-bulb or 87°F at 100% Humidity.

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CHAPTER I: INTRODUCTION

Climate change is increasingly becoming a significant problem, particularly in the urban areas where most of the world's population lives. The materials and methods used to construct buildings and upgrade and expand infrastructures contribute to the increasingly extreme weather events and conditions associated with the long-term shifts in temperature and weather patterns that define climate change. For most of the earth's history, these shifts occurred in cycles triggered by changes in the solar cycle. Beginning in the 19th century, however, human activities emerged as the leading cause of climate change, mainly due to burning fossil fuels, such as coal, oil, and gas. The year 2021 saw deadly extreme weather events across the globe, from widespread wildfires to extreme temperatures, torrential rains, and flash floods. Increasing attention by architects is being paid to the potential effects of climate change on urban environments (Andric et al.,2021). Currently, nearly 50 percent of the world's population lives in cities, but this proportion is expected to rise to more than 60 percent within the next 30 years. Most of the future growth of the urban population is expected to occur in the developing world. At-risk populations in many low-income countries are already exposed to a lack of clean drinking water and poor sanitation, often occupying high-risk areas such as floodplains and coastal areas (Haines et al., 2006). The scientific community is responding to these critical human health and well-being issues through renewed interest in the fundamental processes that govern urban climates and research to improve weather forecasts and urban air quality (Souch and Grimmond, 2006). There has also been a growing desire by planners and architects to develop settlements and build homes that are more energy and water-efficient while at the same time reducing risks to human health and the environment (Mills, 2006). Others noted the significant contribution of the world's major cities to global climate change, the urgent need for energy-efficient infrastructure, and the changing resource consumption patterns

(Hunt, 2004). With such a range of issues to be addressed, it is not surprising that there have been calls for broader participation and more effective interaction between complementary disciplines (Oke, 2006). Thus, it is recognized that urban areas are subject to regional climatic change and constitute an essential component of it.

Climate change leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather events and can lead to unprecedented extremes. In addition, climate, or climatic events, even if not statistically severe, can lead to extreme conditions or effects, either by crossing a critical threshold in social, ecological, or physical systems or by co-occurring simultaneously with other events. Some extreme weather events (such as droughts and floods) may result from the accumulation of weather or climatic phenomena that are not extremes (Field, 2012). Though wildfires often impact wilderness and other less-urban areas, recent fires in California have encroached into more densely populated locations.

Many factors influence confidence in observed and projected changes in extreme conditions. Confidence in observed changes in extreme events depends on the quality and quantity of available data and the availability of studies analyzing this data. Thus, confidence varies across regions and to different degrees. Likewise, confidence in predicting changes (including the direction and magnitude of changes in extremes) varies with the types of extreme events, as well as the region and season considered, depending on the quantity and quality of relevant observational data and model projections, the level of understanding of the underlying processes, and the reliability of their simulations in the models assessed through expert judgment, model validation, model agreement, and ground truthing (Andric et al., 2021). Analyses and simulations of global climate change trends may be either more reliable (for example, at extreme temperatures) or less reliable (for example, in droughts and floods) than some regional scale trends, depending on the geographical uniformity of trends in the given extreme. "Low confidence" in observed or expected changes to a given limit does not imply or exclude the possibility of changes to that limit (Field, 2012).

Evidence from observations collected since 1950 provides insight into cases of extreme change for land areas with sufficient data and based on simulations accounting for recent spikes in temperature, there will likely be an overall decrease in the number of cold days and nights and a general increase in the number of warm days and nights globally. These changes may have also occurred at the continental level in North America, Europe, and Australia. There is medium confidence in the warming trend in daily maximum temperatures across much of Asia. Confidence in observed trends in daily maximum temperatures in Africa and South America generally varies from low to medium. Globally, in many (but not all) regions with sufficient data, there is medium confidence that the length or number of heat waves or heat waves has increased since the mid-20th century (Andric et al.,2021). There were likely statistically significant increases in the number of heavy precipitation events (e.g., 95 percent) in more regions than statistically significant decreases. Still, there are considerable regional and sub-regional differences in trends. There is low confidence that any observed long-term increases (i.e., 40 years or more) in tropical cyclone activity are robust after accounting for past changes in monitoring capabilities. A pole shift is likely in the paths of major tropical storms in the Northern and Southern Hemispheres (IPCC, 2021).

Low confidence is observed in trends in assessments of the likelihood and confidence in the projections. There are three primary sources of uncertainty in the projections: natural climate variability, uncertainty in the parameters and structure of the climate model, and forecasts of future emissions. In general, projections for different emissions scenarios do not differ enormously in the next two to three decades. Still, the uncertainty in the sign of change is relatively considerable during this time frame because the signals of climate change are expected to be relatively small compared to natural climate variability (Oke, 2006). For some extremes (e.g., extremes associated with precipitation), the uncertainty in projected changes by the end of the twenty-first century results from uncertainty in climate models rather than uncertainty in future emissions. For other extremes (particularly global temperature extremes and in most regions), uncertainty about emissions is the primary source of projection uncertainty for the end of the twenty-first century. In the assessments in this chapter, the uncertainties in projections from direct evaluation of multi-model ensemble projections are adjusted by taking into account the models' past performance in simulating extremes. For example, simulating late 20th-century changes in temperature extremes appears to exaggerate their estimation (observed warming of extremes and underestimation of warming of cold extremes), the possibility that some critical processes relevant to extremes are missing or poorly represented in models. A limited number of model projections and corresponding analyzes are currently available for extreme temperatures. For these reasons, the estimated uncertainty is generally more significant than can be assessed from model predictions alone. Low probability and high-impact changes associated with crossing poorly understood climatic thresholds cannot be excluded, given the transient and complex nature of the climate system. Feedback is vital in damping or reinforcing extreme events regarding multiple climate variables (Field, 2012).

Models predict a significant rise in extreme temperatures by the end of the twenty-first century. Increases in the frequency and magnitude of daily warm temperature extremes and decreases in cold extremes will almost certainly occur during the twenty-first century on a global scale. Likely, the length, frequency, and intensity of heat waves will increase over most land areas. For the Special Report on Emissions Scenarios (SRES) and A2 and A1B emissions scenarios, a 1-

in-20-year annual hottest day is likely to become a 1-in-2-year annual extreme by the end of the 21st century in most regions. These predictions will affect all regions except in the northern hemisphere's high latitudes, where the maximum is likely one year out of five. In absolute terms, the 20-year maximum daily maximum temperature (i.e., the return value) is likely to increase by about 1 to 3 °C by the middle of the 21st century. About 2 to 5 °C by the late 21st century, depending on the region and emissions scenario (Considering scenarios B1, A1, B, and A2). Regional changes in temperature extremes often differ from the average global temperature change (Ballester et al., 2010).

Changes in the limits can be related to changes in the mean, variance, or shape of the probability distributions. Thus, a change in the frequency of hot days can arise from a change in the mean daily maximum temperature and a change in the variance and shape of the frequency distribution of daily maximum temperatures. Suppose changes in the frequency of occurrence of hot days are primarily related to changes in average daily maximum temperature, and changes in the shape and variability of the distribution of daily maximum temperatures are of secondary importance. In that case, it may be reasonable to use expected changes in average temperature to estimate how Changes in extreme temperatures can change in the future. However, if changes in the shape and diversity of the frequency distribution of the daily maximum temperature are significant, such a naive extrapolation would be less favorable or possibly misleading (Ballester et al., 2010).

The results of both empirical and model studies indicate that, in many cases, changes in extremes are closely proportional to changes in the mean (Griffiths et al., 2005). There are reasonable exceptions to this that changes in variance and form must account for probability distributions of weather and climate variables and changes in means in extreme events (Orlowsky and Seneviratne, 2011). Indeed, recent publications and public debate have focused on global mean temperature targets (Meinshausen et al., 2009); however, the exact effects of these mean global changes (the '2°C targets') of regional extremes have not been evaluated in a wide range (Clark et al., 2010). It should also be noted that regional extremes do not necessarily expand with global mean changes but also mean that global warming does not exclude the possibility of cooling in some regions and seasons, both in the recent past and in future decades: for example, it has been suggested that the decrease in ice Maritime-induced average warming could, although not systematically, increase the frequency of cold winters on the northern continents (Petoukhov and Semenov, 2010).

Climate change can be expected to lead to changes in climate and extreme weather. But it isn't easy to associate a single extreme event with a specific cause, such as an increase in greenhouse gases, because a wide range of events can occur even in a stable climate and because a combination of factors usually causes extreme events. In addition, climatic or climatic events, even if not statistically severe, can lead to extreme conditions or impacts, either by crossing a critical threshold in a social, ecological, or physical system or by co-occurring simultaneously with events other. A weather system like a tropical cyclone can have a severe impact, depending on where and when it approaches land, even if the specific cyclone is not as severe as other tropical cyclones. On the contrary, not all extreme events necessarily lead to dangerous effects (IPCC, 2012).

Natural climatic fluctuations cause many climate extremes, and natural decadal or multidecadal changes in climate provide a background for anthropogenic climate changes. Even if there were no anthropogenic changes in climate, a variety of natural and extreme weather events would still occur (Nicholls et al., 2012). Scientists monitor changes in the earth's climate in every region and across the entire climate system. According to a recent Intergovernmental Panel on Climate Change (IPCC) report, many climate changes have not been seen for thousands, if not hundreds of thousands of years. Some changes (IPCC, 2021), such as the continuous rise in sea level - are irreversible over hundreds to thousands of years and have already begun.

However, substantial and sustained reductions in carbon dioxide emissions and other greenhouse gases would limit climate change. While the benefits of air quality will be realized quickly, it could take 20-30 years for global temperatures to stabilize, according to the report of the first working group of the Intergovernmental Panel on Climate Change.

Atmospheric carbon dioxide concentrations were higher in 2019 than at any point in at least two million years. The earth's surface temperature has risen faster since 1970 than in any other 50 years in at least the past 2,000 years (IPCC, 2021). The report provides new estimates of the chances of exceeding the level of global warming of 1.5°C in the coming decades and concludes that unless there are immediate, rapid, and widespread reductions in greenhouse gas emissions, limiting warming to approximately 1.5°C or even two °C will be beyond reach (IPCC, 2021). The report states that greenhouse gas emissions from human activities are responsible for about 1.1°C of warming since 1850-1900 and finds that, on average, over the next 20 years, global temperature is expected to reach or exceed 1.5°C of warming. This assessment builds on improved observational data sets to assess historical warming and advances in scientific understanding of the climate system's response to human-caused greenhouse gas emissions.

Many characteristics of climate change depend directly on the level of global warming; for example, global warming is twice as high in the Arctic. Climate change is already affecting every region on earth in multiple ways. The changes we are experiencing will increase with increasing warming. The report predicts that climate change will increase in the coming decades in all regions.

For global warming of 1.5 degrees Celsius, there will be an increase in temperatures, longer warm and shorter cold seasons. The report shows that at two °C of global warming, extreme temperatures will often reach critical tolerance thresholds for agriculture and health. But it's not just about temperature. Climate change is causing many changes in different regions - all of which will increase with increasing warming. These include changes in humidity, drought, wind, snow, ice, coastal areas, and oceans.

Climate change affects precipitation patterns. At higher latitudes, precipitation is likely to increase, while it is expected to decrease in large parts of the subtropics. Changes in seasonal precipitation are expected, which will vary by region.

Climate change is the crisis of this age. The climate is changing rapidly due to many variables as the built environment contributes to the global climate change crisis, mainly due to greenhouse gas emissions from human activity. These anthropogenic gases are derived partly from aspects of the built environment, such as transportation systems and infrastructure, building construction and operation, and land use planning (Younger et al., 2008). Buildings contribute to climate change, transportation, and health through materials, site decisions, electricity, water use, and the surrounding landscape. Land use, forestry, and agriculture also contribute to climate change and affect health by increasing carbon dioxide levels in the atmosphere, shaping transportation and building infrastructures, and affecting access to green spaces. Vulnerable populations are disproportionately affected in terms of transportation, buildings, and land use, and they are most at risk of experiencing the effects of climate change. Working across sectors to incorporate health promotion approaches into designing and developing components of the built environment may mitigate climate change, promote adaptation, and improve public health.

Since the built environment contributes to climate change and health outcomes, alternative practices provide opportunities to improve health and reduce climate change (Younger et al., 2008).

Global carbon dioxide emissions from energy use in buildings grew by approximately 3% annually between 1999 and 2004; the predominant energy source consumed by the electric power sector produced 83% of US carbon dioxide emissions in 2006 and contributed to methane emissions as well (Brown et al., 2005). Buildings influence greenhouse gas emissions through various aspects of their design, location, orientation, and use, such as their relationship to each other and the adjacent landscape, the material composition and design elements of their interior and exterior parts, and the energy and water resources used by their occupants. A building's energy use is also affected by the characteristics of its surroundings (such as sunlight, wind, trees, and water), which in turn affect greenhouse gas emissions (US Department of Energy, 2007).

Various aspects of construction affect the health of users. For example, hospital design characteristics, such as better lighting, planning, and ventilation, have reduced stress and fatigue in patients and staff and improved overall health. Whether commuters must rely on cars or be able to walk, cycle, and use public transportation to other destinations has been shown to impact BMI (Pendola et al., 2007) significantly.

Decisions to use sustainable building materials and operating practices can promote health and protect the environment by mitigating the effect of urban heat islands, conserving resources, and allowing safe disposal of polluting or hazardous waste. Environmentally friendly supplies (e.g., recycled materials) can be replaced with products that use non-renewable resources. Buildings constructed with locally produced materials support local economies and reduce air pollution associated with transportation (Smart Communities Network, 2004). In addition, building and landscaping designs can encourage routine physical activity by providing attractive, accessible staircases with clear signage and outdoor walking paths. The design and built environment contribute to a 40% reduction in carbon dioxide, disproportionally a considerable contributor to global climate change. So, we are under pressure to reduce the contributions of the design and built environments to global climate change. The pressure to develop new ways of designing architecture leads us to look to nature and indigenous science for answers (Eves & Webb, 2006).

Rising global temperatures are causing climate-related natural disasters, and buildings are one of the biggest culprits in plain sight. In total, buildings account for about 40% of annual fossil fuel carbon dioxide (CO2) emissions, adding to floods, fires, hurricanes, and billions of dollars in annual damage. It is a global emergency of our own making. And if we don't take action now, we will help accelerate global warming — irreversibly changing life as we know it (Younger et al., 2008).

In recent years until 2021, understanding how much carbon buildings contribute has been a data problem. The government and other agencies have reported less than 40% of carbon dioxide emissions for years. That changed when Ed Mazria, FAIA, an architect in Santa Fe, New Mexico, founded Architecture 2030, a nonprofit initiative to transform the global built environment from a significant contributor to greenhouse gas (GHG) emissions to a central part of the solution to the climate crisis. While transportation grabs many headlines around carbon dioxide emissions, surprisingly, it only accounts for about 23% of global emissions. By contrast, construction processes, materials, and the construction sector cause most of the rest (IPCC, 2021).

For architects, this challenge represents a pivotal opportunity in design, planning, and construction - an opportunity to tackle carbon immersion, dramatically reduce carbon dioxide emissions, and shape the future of our world. Large groups of people are rapidly changing their lives to make an impact, resulting in a dramatic decrease in nitrogen dioxide (NO_2) in China (IPCC, 2021). Likewise, architects can quickly change how they design buildings to impact climate change positively. To support this mission, the American Institute of Architects- the world's largest design organization-is asking architects, design professionals, and civic and public leaders to join our efforts and achieve a carbon-neutral, resilient, healthy, fair, and just goal environment (IPCC, 2021).

Temperatures are increasing yearly, and the designed and built environment contributes to that warming. Species that have thrived in scorching environments and human societies inhabiting extremely hot regions for centuries inspire architects as they confront the challenges of designing for hotter conditions while reducing buildings' contributions to those hotter conditions.

The world is treading on dangerous grounds, and from other climatic forecasts, the earth will have experienced massive damage in the next thirty years. As the only planet known to sustain life, earth has all the resources to enable humans to live in peace and sufficiency. However, like the proverbial message that the ground is eating its children, human beings are destroying the one place that is safe for them (Tuner,2008). There have been massive climatic changes during the twenty years that have been majorly attributed to the idea of modernism. The world has critically changed, and lives are being threatened.

Technology is a vital resource that has significantly changed the lives of individuals. Technology is a significant asset in health, education, business, and production industries. Interestingly, technology is yet to reach its peak, and more advancements are expected to be observed shortly. While these changes likely make individuals happy, they create an environment that will hardly sustain lives. Environmental pollution has massively increased with technological advancements (ElDin, 2016). Traditionally, individuals appreciated using natural resources and ensured that they protected and supported the environment. However, the same is not being observed in the current generation. People are using technology to destroy natural resources, thus threatening many lives.

Cases of people in developing countries complaining of hunger and lack of clean water are reported daily. Human impact on climate and resources has severely restricted the availability of and access to sufficient food and water supplies in many regions, causing unprecedented suffering. Poor sanitation is also a concern due to improper disposal of industrial waste. While such issues are defined as common issues and individuals have become used to hearing such cases, the issues regarded as minor at the moment will soon be a global concern.

Urban centers are known to hold a significant position in climatic changes. Urbanization promised more economic opportunities for people migrating from poor rural areas, but the contributions of rapid development and urbanization have not had the intended positive impact. (Primrose, 2020). Many companies and organizations are moving to rural areas to introduce urbanization as business opportunities continue to rise. However, urbanization dramatically impacts the environment that individuals are let in. It is essential to focus on the future and determine what the consequences of one's current actions are in the future.

One particular sector that has created concerns while dealing with environmental concerns is the construction industry. Architects are developing plans that see the rise of significant buildings. One crucial question that architects need to ask themselves is how their plans are affecting the environment. Significant buildings consume much energy, some of which is emitted into the air as particulate matter. Global warming is also occurring because of the poor disposal of waste. Buildings are being developed using destructive methods rather than implementing constructive approaches.

To provide a theoretical and critical framework through which to better characterize the damage inflicted on the planet by the destructive exploitation of resources, philosophers such as Levi Bryant have proposed a “wilderness ontology.” According to Bryant, “the central claim of wilderness ontology is that the wilderness is all there is” and humans and human civilization have not been a part of wilderness (Bryant, 2022). Implicit in wilderness ontology is the notion that human cities are equivalent to wasp nests, beaver dams, and the nests of Bower birds—the major distinction being that wasps, beavers, and Bower birds do not willfully destroy their habitats and poison their food and water sources. This philosophical perspective invites architects to rethink the nature-culture divide, providing architects an opportunity to develop designs that mimic other species. This biomimetic approach refers to the emulation of naturally occurring forms, features, materials, and behaviors to design for humans (Helfman, 2014).

One primary concern in human disruption of the wilderness is the extreme rise in global temperatures. As a direct result of human activity, many regions are expected to observe extreme temperatures (Mead, 2008). Climate scientists in areas of the world not previously known for record-breaking heat and cold have recently begun to record temperatures that put human life at risk. Mechanical heating and cooling systems rely on electricity generated by fossil fuels, adding greenhouse gases to the atmosphere and contributing to global climate change. Architects now face a future in which the construction of human habitation in predominantly urban areas will decrease the earth’s habitability as temperatures continue to rise in some areas, causing deaths from hypothermia in other regions.

The biomimetic approach to handling extreme temperatures is a solution where architects and scientists study the behavior of plants and animals during extreme temperatures and use the information gathered to develop housing designs (Primrose, 2020). When considered in terms of lifecycle embodied energy and lifecycle embodied carbon, structures intended to shelter humans play a major role in rendering some areas unfit for human habitation. The impact on plant life, water resources, and non-human species intensifies the gravity of the situation. Urban heat islands also factor into these ongoing cycles of design, construction, occupancy, energy consumption for thermal comfort, and greenhouse gas emissions., As temperatures continue to rise, controlling the interior thermal condition of buildings becomes increasingly difficult. Biomimetic design offers an approach that will enable architects to develop resilient designs and ensure that humans do not cause their extinction.

Urbanization and technology are irreversible conditions., The impact of technology and urban planning can be mitigated and even reversed through the strategic implementation of biomimetic design principles (French, 2010). Architects and scientists have the opportunity to look deep into pre-industrial vernacular housing materials and methods in the human-inhabited regions that have traditionally recorded the highest and lowest temperatures by observing the adaptations and behaviors of non-human species. Framing biomimetic design practices in the recognition that everything is wilderness and that humans have always only been a part of that wilderness may help to eliminate the nature-culture divide that has produced the current global climate crisis. The goal is not to rebuild the world but to create ways to make the world a better place by using natural solutions.

This dissertation considers biomimetic design from three perspectives. First, it applies qualitative case-study analyses to determine whether existing biomimetic approaches and indigenous science can reduce architecture's negative environmental impacts. Second, it considers whether applying biomimetic design principles and indigenous science can protect humans in areas that are becoming less habitable because of extreme temperatures. Finally, the dissertation evaluates whether biomimetically designed structures can shelter humans without contributing to global climate change.

1.1.Background

Climate variability is part of the earth's natural rhythms and cycles. According to NASA, the earth's climate has been evolving steadily throughout history, with seven cycles of glacial advancement and retreat happening over the last 650,000 years. The end of the most recent ice age, which occurred about 11,700 years ago, marked the onset of modern climate change. Notably, a significant portion of climate change in the earth's history is attributable to changes in solar energy received by the earth and minor variations in the earth's orbit (NASA, n.d.). Today, human activity, which includes operations in the built environment, is the primary driver of climate change. Since the first quarter of the twentieth century, the International Style, comprising structures built primarily with concrete, glass, and steel, has dominated architecture (Corbusier, 2013). The emergence of the International Style marked the crystallization of modernism in building design and the operationalizing of Pierre Jeanneret's "a house is a machine for living" manifesto. Jeanneret, more popularly known as Le Corbusier, generated an architectural style characterized by pilotis, open and free-flowing floor plans, strip windows, and rooftop gardens (Oechslin, Werner, 1987; Moreira, Susanna, 2020). Globally, concrete is one of the largest sources of carbon dioxide emissions. The manufacture of cement, a major component of concrete, produces a significant amount of carbon dioxide produced by human activities. Concrete – of which cement makes up 10-15% of the mixture – is responsible for about 4-8% of global carbon dioxide emissions, according to London-based think tank Chatham House. Glass and steel production are also significant sources of emissions. This new architectural and building design approach moved away from ornamentation. They focused on new definitions of form and function, with a homogenizing aesthetic intended to erase vernacular traditions, ignore natural site conditions, and substitute machine function for conventional modes of domesticity.

While architects adopted the International Style to their built environment across the globe from the mid-20th century, its effects on the climate have only recently begun to be an issue of concern among industry practitioners. A recent empirical study compared the global-warming potential of materials used to construct the walls of houses built in traditional, semi-modern, or modern styles. The study established that traditional houses released a quarter of greenhouse gas emissions (GHGs) from semi-modern houses and less than a fifth of GHGs emitted from modern homes (Bhochhibhaya et al., 2017). These findings indicate that materials used to build modern houses' walls contribute the most to GHG emissions that lead to global warming. Given that modern houses are dominated by the international style of Le Corbusier, the glass and concrete used on the walls worsen global warming. The study's findings also indicate a significant disconnect between construction practices and nature (Bhochhibhaya et al., 2017). That is, widely adopted building practices exacerbate global warming rather than reduce it. The Brutalist style, which privileges exterior concrete surfaces and exposed concrete in architectural interiors, has exacerbated the link between climate change and the designed and built environment. The adverse effects of modern and contemporary architecture on climate change remain a growing cause for concern. As this dissertation will demonstrate, the significantly lower negative impacts of traditional building materials on global warming offer new opportunities for building and construction using less harmful materials, indigenous building methods, and biomimetic techniques.

1.2.Research Problem

The imitation of nature is well positioned to play a central role in efforts to solve problems related to health, energy efficiency, and food security. To realize these promises, researchers working in these fields must benefit more from the knowledge and experience of biologists. The field of biomimetics often includes chemists, engineers, and materials scientists. Of the nearly 300 biomimetic studies, less than 8% had one author working in the biology department. In most biomimetic research, biodiversity has not received sufficient attention. For example, in more than 80% of the papers published on biomimetics during a given year, researchers have limited their attention to just one species superfluously. And to add to that, in most studies of various stages and systems, only the same species appear as geckos, spiders, and butterflies. Although simulation of nature by devices and systems appeared tens of years ago, hundreds of years ago, man observed nature and its systems, animals, and plants. Therefore, many legends and stories of history that rely on mimicry of nature can be heard. One of the first studies of nature simulation is a study on birds so that humans can fly. The Wright brothers invented the first heaviest plane in the air and used the carrier pigeon.

In 1960, "Jack Steele" developed a new term, "electronic biology," to define the subject as a science inspired by natural systems. In 1974, the term "biomimicry" became in Webster's dictionary. In 1997, biomimicry became a more widely used scientific term after the publication of the first book devoted to this science. It was under the name - Innovation Inspired by Nature, which means "innovations inspired by nature," by the American scientist and writer Jeanine Benyous (Aanuoluwapo, 2017).

The anthropocentric belief has mainly driven architects' approaches to the built environment that humans are the most important among living things. Thus, the needs of human beings supersede those of other living things (Kopnina et al., 2018). Environmentalists argue that anthropocentrism is unethical and is at the root of all ecological, environmental, and climate crises modern society faces (Kopnina et al., 2018). The view that human needs and aspirations are superior to other organisms has allowed humans to undertake actions that harm the environment and climate. The international style of building design and construction continues to be widely practiced across the globe since it is considered the epitome of modernism within the built environment. The desire for modern buildings has driven humans to design and construct houses contributing to global warming continuously.

The Anthropocene is a proposed epoch that dates to the onset of significant human influence on earth's geology and systems, including, for example, anthropogenic climate change. The Anthropocene functions as a geological unit of time, a continuous process, and a new, different, distinct stratum (Subramanian, 2019). Various dates have been suggested for the Anthropocene, ranging from the start of the agricultural revolution 12,000 to 15,000 years ago to the most recent Trinity test being made in 1945. From February 2018, the validation process continued, so the date remained and then decided conclusively, but the latter date was more favorable than the others. Crutzen suggested the Industrial Revolution as the beginning of the Anthropocene. Lovelock suggests that the Anthropocene began with the first application of the Newcomen atmospheric engine (the first practical fuel-burning engine) in 1712. The IPCC takes the pre-industrial era (chosen in 1750) to form a baseline regarding changes in long-lived greenhouse gases. Human activities have profoundly modified much of the terrestrial landscape, though the Industrial Revolution has declared an unprecedented global human impact on the planet. Man's influence on earth gradually increased, with only a few actual depressions. The Anthropocene is assessed as a potential new unit in the international chronostratigraphy (which serves as the basis for the geological time scale) in terms of stratigraphic signs and approximate boundary levels available to define the unit's base. At the same time, the challenges facing the earth due to human activity are as follows (Subramanian, 2019)

- Erosion and movement of sediments in the oceans, soil transport resulting from agriculture, urban expansion, and mining.
- Anthropogenic disruption of elements such as carbon, nitrogen, and phosphorous cycles.
- Environmental changes resulting from this imbalance, such as global warming, rising sea levels, ocean acidity, and the spread of dead zones in the oceans, are those in which oxygen is reduced due to pollution.
- The accelerated change of the biosphere on land and sea resulted from the decline of the natural habitats of living organisms, overhunting, the digital explosion of poultry and grazing animals, and the phenomenon of invasive species.
- The extensive spread and worldwide use of many minerals and rocks, including cement and smoky ash resulting from burning waste, and the geological signs they will leave that will persist in the rocks for millions of years (Steffen et al.., 2011).

Therefore, we are facing a new consciousness that is forming; the Anthropocene era will push this awareness forward a vital distance, enabling scientists to exert more substantial pressure. Here we can recall that the term Anthropocene was initially proposed by the Dutch atmospheric chemist (and Nobel Prize winner for chemistry) Paul Crutzen in a scientific paper he published in 2000. A significant part of the Anthropocene is that consciousness creates a unique culture, and culture, in turn, creates a new consciousness. Consciousness is the awareness of the idea that we humans are not essential to life but are contingent and can quickly end as other types of life end. Some species may be more fortunate than us, as they have been going on for millions of years. Natural imbalances caused the great extinction that occurred (225) million years ago and the cause of the extinction wave that occurred in the Tri-Cretaceous period that ended the life of the dinosaurs. However, humans at this time are likely to cause an extinction wave that may start at any moment due to the massive depletion of resources and the endless pollution of the planet (Autin, Whitney & Holbrook, John, 2012) (Zalasiewicz et al., 2010).

Infrastructure, environment, and life in the Anthropocene explore life in the age of climate change through a series of infrastructure puzzles - locations where it has become impossible to separate nature from the built environment. With topics ranging from breakwaters built of shellfish, underground rivers made by leaking pipes, and architecture transformed into neighborhoods partially submerged by the rising tide, contributors explore situations that destabilize the concepts we once relied on to address environmental challenges. "They take on the Anthropocene challenge to life on this planet and our socio-scientific understanding of it by showing how past notions of the environment and progress have become unconstrained and what this means for how we imagine the future" (Chester et al., 2019).

The effects of global warming are worst in scorching environments where further increases in temperature through climate change may upset entire ecosystems. This problem calls for a shift from an anthropocentric belief system to an eco-centric belief system.

An eco-centric belief system eliminates the hierarchy of needs that prioritizes human needs over other organisms. Instead, it views the needs of all living organisms as equal and encourages experts to reconsider their building practices and adopt those that cause minimal environmental harm (Shastri, 2013). By analyzing the studies related to the research topic, we find that most studies focused on nature by simulating its form and environmental effects to achieve sustainability. Still, they dealt with specific aspects of it, whether creating architectural forms that approach form and action and in the behavior of natural forms in their ability to adapt to surrounding conditions. The existing research does not address examples of biological systems and indigenous sciences from the past and present to help architects improve thermal comfort in currently hot environments and in the future. Therefore, the research problem lies in the lack of sufficient studies on the importance and role of simulating living natural systems in the built environments.

In this context, this study assesses the usefulness of biomimicry as a sustainable approach to tackle issues of currently hot environments by observing indigenous cultures, which survived and thrived under these conditions, along with other species that accomplished the same living strategies in similar climates. The study then expands to the future of high-temperature regions, which are expected to become more extreme with rapid climate change. Even though we have vernacular architecture, indigenous science, and examples of architecture in current hot environments, nobody's designing to keep people from dying as temperatures continue to rise.

1.3.Research Question

The main question of this study is: **Can examples of biomimetic and indigenous science help architects reduce the indoor temperature in the GCC climate?**

This central question is subdivided into the following sub-questions:

1. Can architects and designers harness the principles of biophilia, biomimicry, and indigenous building practices to design buildings that protect occupants from increasingly extreme temperatures?

2. Are there enough countries/projects in the GCC region that are using biomimetic and vernacular solutions into consideration while also working on reaching the targets promised in accordance to the Paris Agreement?

1.4.Research Objective

This dissertation aims to determine whether combining biomimetic design with vernacular architecture from the Middle East can inspire architects to design buildings that protect occupants from extreme temperatures without contributing to the continuing rise in temperature.

This main objective is subdivided into the following sub-objectives:

1. To encourage architects to combine principles of biomimicry with indigenous practices to design architecture for environments that are becoming extremely hot.
2. To ensure that cities in the Middles East do not continue to discard their identity for the sake of urban modern expansion.

1.5.Research Significance

This dissertation suggests a combined design concept that might protect humans from the effects of global warming. Reviewing the literature on the subject signified the gap that there is extensive research on vernacular architectural conditions, biomaterials, and indigenous science traditions. But none of the newly developed projects in the Middle East has combined the three principles to create a sufficient solution to the problems that human tolerance for hot temperatures is not as high as previously predicted and the loss of cultural identity.

Because nature is a fertile field full of aesthetic values and vocabulary that provokes creativity and enriches it with experiences and successful solutions despite circumstances over time, it is a valuable source for those who study, analyze, and simulate it with contemplation and scrutiny. Because indigenous groups and non-human species have lived in harmony with the wilderness without degrading their natural habitats, indigenous architectural practices and biomimetic design principles offer an alternative to the architecture, construction materials, and methods that contribute to global climate change.

The first humans who were able to observe nature closely were our ancestors, indigenous cultures. They were the first to apply principles of mimicry in their habitat and social cultures. They lived in harmony with the environment, understating the importance of sustaining the earth's resources while using only what they needed and what was available. Learning from both nature and vernacular solutions will help architects in designing architecture for a future extreme world.

The importance of this study comes from the significance of biomimicry and vernacular architecture, which represents a worldwide issue and an important area of research. Studies of biomimicry in architecture for hot environments are few. Therefore, conducting such research on the topic is expected to have high positive reflections and significance as follows:

1) The importance of research comes through providing a guideline for architects who intend to design in the Middle East with the strategies that work and don't work in this region.
2) The scientific importance of this study lies in the shortage of studies that specifically dealt with biomimicry in architecture for historically and currently hot environments, making this study a new scientific attempt to identify the issue and develop appropriate scientific recommendations.

3) One of the most significant benefits of this study is that we need to look beyond technology and conventional Western architectural practices to anticipate and accommodate the extreme temperature fluctuations we currently encounter and are expected to in the future.
4) There has never been an architectural project that combined biomimetic design principles and vernacular architecture solutions to face the urgent issue of protecting human life due to rising temperatures.
5) Modern buildings practice relies on mechanical equipment as technologies to achieve thermal comfort without learning from building science technologies inspired by vernacular architecture.

1.6. Constraints of Research

Defining extreme environments in the scope of this research:

What is *extreme*? For a human who lives in the Atacama Desert, extreme weather might be living in the dry valleys of Antarctica and vice versa. The extreme environments mentioned in this dissertation would be the predicted climate of planet earth. The Cambridge English dictionary defines extreme as very large in amount or degree.

Resent research by PennState University discovered that humans are less tolerant of high heat and humidity than previously believed. It has long been thought that a person could only withstand temperatures of 35°C wet-bulb (equivalent to 95°F at 100% humidity or 115°F at 50% humidity) before losing the ability to control their body temperature, which might lead to heat stroke or death over time. However, even for young, healthy persons, the real maximum wet-bulb temperature is lower — around 31°C wet-bulb or 87°F at 100% humidity. The temperature is probably much lower for elderly populations, who are more susceptible to heat (Bohn, 2022).

According to the Intergovernmental Panel on Climate Change (IPCC), the probability of extreme weather events associated with global warming is increasing. It alerted ecologists to the potential for more frequent or severe disturbances to ecological communities due to droughts, storms, unprecedented rains, heat waves, fires, and abrupt changes in ocean circulation (Drijfhout et al., 2015). Climate modelers predict that extreme weather events will increase with global warming. As the mean temperature increases, extremities may become more extreme, possibly more frequent, and thus less rare (Stocker, 2015).

Qualitative assessment methodology:

The real constraint is that there aren't any existing architectural projects that were built in the way this research suggests. There haven't been any architectural projects that integrate natural inspiration, vernacular solutions, and biomimetic modern technologies to protect humans from the future climate that keeps increasing. Therefore, a qualitative case-study-based methodology was selected to cover the bases for this new approach as the case-study method. To generate the "more formal" instruments required in surveys and experiments, case studies have frequently been seen as a valuable tool for the initial exploratory stage of research.

1.7.Expected Results

This research expects to assess the extent to which architects can combine indigenous practices with biomimicry technologies to design buildings that will protect humans from increasingly extreme temperatures while reducing the contribution of the designed and built environment to global climate change. The results will include an overview of the latest architectural projects in the GCC countries to assess the pledges they made as targets in response to the Paris agreement. The second expected result is a cumulated guideline for building in this region, especially for the increasingly hot future. Third result to be expected is examples that qualify Vernacular and biomimetic technologies to reduce heat in the built environment. Finally, this research expects to encourage twenty-first-century architects to invoke, synthesize, and implement biomimetic and vernacular building practices to design and construct buildings suitable for hot environments without exacerbating temperature increases.

CHAPTER II: LITERATURE REVIEW

2.1.Introduction

Extreme weather events are gradually becoming more common across the planet. The increasing frequency with which extreme weather events occur is an issue of concern among architects. According to the latest report by the United Nations Office for Disaster Risk Reduction (UNDRR), rising global temperatures are mainly responsible for the significant increase in extreme weather events (UNDRR, 2020). Between 2000 and 2019, 7,348 major natural disasters have killed over a million people and caused economic losses worth $2.97 trillion globally. In comparison, in the prior twenty-year period (1980-1999), 4,212 natural disasters occurred worldwide, claiming about 1.2 million lives and causing economic losses worth $1.63 trillion (UNDRR, 2020). The same report further notes that comparing the two 20-year periods reveals that flooding more than doubled, severe storms increased by 40%, and heatwaves, wildfires, and droughts increased. A report by the European National Science Academies concurs that the frequency of extreme weather events has increased and urges national governments to formulate policies to adapt to and mitigate the causes of climate change (European Academies Science Advisory Council, 2018). Such procedures could target economic sectors, such as the building and construction industry, contributing to climate change via Green House Gas (GHG) emissions.

The UN Secretary General's Special Representative for DRR stated in a statement that "we are willfully destructive" after releasing a report on climate change, revealing that human activity is primarily to blame for global warming and climate change. Human activity in urban areas adversely affects the environment. Studies comparing rural areas and urban area climates have found differences (Luca, 2017). Researchers have found that temperature is a significant factor in shaping these two areas' climates (Popescu and Luca, 2017). Temperature is directly connected to human activity in the built environment in cities and is partly responsible for GHG emissions, global warming, and climate change (Popescu and Luca, 2017). Tall buildings in urban areas have glass that reflects and concentrates sunlight. They also have concrete that absorbs the sun's energy, heats up, and re-radiates the energy, warming up the surrounding environment. The rising temperature of the surrounding environments harms nature and potentially upsets ecosystems and natural ecological balances. Despite the harmful effects of the built environment, many regions worldwide rely on the international style to design and construct buildings.

The continued adoption of the international style in building and construction, despite its effects on the environment, particularly in sweltering climates, can be attributed to the anthropocentric belief that prioritizes human needs over other living things. For several centuries, experts in the built environment have viewed infrastructure as separate from natural systems. Modernist cities were built around that concept that is now inhabitable. Chandigarh City in India, designed by Le Corbusier, is an example of a failed project of the international style. Such one does not connect to its surrounding environment and is no longer tolerable. As the scale and scope of human activities have increased, the dichotomy between natural systems and infrastructure has reduced. Natural systems are increasingly becoming part of human design spaces, as in managing wildlife, forests, and hydrologic systems that supply urban water needs (Chester et al., 2019). Despite the narrowing divide between natural systems and human design spaces over time, the anthropocentric view still dominates the design field, often with detrimental effects on the environment. Architects devise new ways of using urban spaces to suit human needs with little regard for the impact on the surrounding ecosystems. There is a growing need for practitioners to discover new ways of reducing the overall effect of the built environment on the earth’s environment and climate. One particular focus point, in this regard, is building materials used in the construction of modern houses based on the international style. Glass, asphalt, and concrete contribute to global warming and climate change (Popescu and Luca, 2017). Considering that these materials are predominantly used in modern buildings, studies looking at alternatives are desirable.

Biomimicry is a concept that has been implemented in various fields since the beginning of human evolution to this day (The Biomimicry Institute, 2021). Although very impactful in disciplines, it has not yet been used in sustainable architecture in the necessity the world currently demands and not specifically in hot environments. Following the hypothesis by Edward O. Wilson, which he calls The Biophilia Hypothesis, humans constantly seek connection with the living world (Clowney, 2013). Biophilic design is a holistic approach, which would be the translation of correctly designed biomimetic architecture.

Biomimicry is the science of copying natural systems and designs to create new industrial products (Benyus, 1997). The concept or term biomimetics was created by the American academic inventor Otto H Schmitt, who explained all studies, mechanisms, methods, and processes related to the concept of mimetics. This term is derived mainly from the combination of two words, the first (bios), which means life in the Greek language, and the word (mimesis), which means imitation (Schmitt 1969). The science of mimetics is the copying of natural materials of structures and functions of biologically produced materials (such as enzymes and silk) and biological mechanisms and processes (such as protein synthesis and photosynthesis processes) to produce industrial products and artificial mechanisms (artificial) similar and simulating their natural counterparts other. Mimicry is also a test of nature and its models, systems, processes, and elements to compete with humans and be treated with inspiration to solve human problems. Biomimetics is also defined as the science that studies the structures and actions of ecosystems with the aim of designing and engineering materials (Schmitt 1969).

Nature has stimulated human achievements throughout the ages and has led them to effective structures, tools, materials, mechanisms, processes, methods, and systems. This field of knowledge, known as biomimetics, offers tremendous energy for new energies intending to reach exciting future technology. When looking at natural creatures as an engineering design, they will outperform their industrial and commercial counterparts in many general aspects and remarkable capabilities. In complete contrast to manufactured designs and engineering structures that require accurate repetition, like their work, living organisms will have the ability to perform their work optimally. They can identify and distinguish each organ with the same biological type (Elgawaby, 2010).

Understanding what "indigenous science" means and why it is vital as a cornerstone for creating an indigenous approach to the contemporary and future construction of Indigenous communities is essential. Knowledge development through indigenous sciences is guided by spirituality, moral relationship, reciprocity, respect, self-control, focus on harmony, and recognition of interdependence. This knowledge is combined concerning a specific person and 'place' towards the goal of sustainability and the perpetuation of culturally distinct lifestyles across generations. Indigenous science is conceived of in a global, "high-context," and relational perspective that includes all relational connections in a dynamic equilibrium that is interdependent in its primary considerations and activity (Sheehan, 2004). In contrast, Western science sees from the "low context" point of view, minimizing context with an emphasis on material objectivity, logic, and reproducibility (Wolfgramm, 2007).

The working definition of "indigenous science" is "that body of unique traditional environmental and cultural knowledge of a group of people that have served to support those people through generations of living within a distinct biome." It is based on a body of practical environmental knowledge learned and passed down through generations through some form of environmental and cultural education unique to them. Indigenous science is indigenous knowledge and can also be called "traditional environmental knowledge" (TEK) since a large proportion of this knowledge serves to sustain indigenous communities and ensure their survival in the environmental contexts in which indigenous communities are located (Cajete, 2000).

Indigenous science can also be defined as a "multi-contextual" system of thought, action, and direction applied by indigenous people through which they explain how nature operates in their "place." Indigenous knowledge can be defined as a body of 'highly contextual' knowledge accumulated through generations by culturally distinct people who live in close contact with a 'place' and its flora, fauna, waters, mountains, deserts, plains, etc. Indigenous science (in its expression as traditional ecological knowledge (TEK) integrated with appropriate insights and models from the evolving field of "sustainability") offers possibilities for innovative models for indigenous communities to preserve themselves and their cultural ways of life in the twenty-first century (Gregory, 2020).

Indigenous science is studied and introduced in this research because the people who constructed their homes and communities were inspired by nature. They use local materials, observe surrounding animals and insects, and achieve thermal comfort indoors without isolating the outdoors, creating vernacular architecture. Case studies like the wind catchers in vernacular architecture and the mounds in structures built by termites demonstrate that both species that lived in similar environments have devised solutions to the same problems: strategies to achieve thermal comfort in hot climates (Khoja and Waheeb, 2020). So, indigenous science could provide the knowledge humans need to bridge the gap between architecture and nature.

Michael Pawlyn is one of the most influential architects in biomimicry as it relates to architecture. His book *Biomimicry in Architecture* mentions concepts and examples of successful previously designed architectural projects and predicted future work for designers. Unfortunately, none of the designs showcase examples of extreme architecture following biomimetic principles. However, other programs exist that offer hope in addressing this problem. For instance, the living building challenge seeks to make all building design and construction projects positively affect the world (Living Future Institute, 2021). The challenge focuses on the relationship between impact and effort and seeks to use regenerative designs consistent with the principles of biomimicry to achieve the overarching goal. Considering the complex nature of the challenges experts face, any effort to develop new approaches to design and construction that minimize the negative effect of the built environment and ensure the best investment is welcome. The School of Complex Adaptive Systems in Arizona State University focuses on developing frameworks to guide the design of systems on the planet in a highly technical way; it also integrates these frameworks into social and conceptual designs. There needs to be a cultural shift to encourage people to invest in biomimetic solutions by showing them how regeneration will improve their conditions. Additionally, investing money in demonstrating the value of finance and implementing renewable and efficient systems inspired by the natural world rather than many of the current non-adaptive solutions will help.

Emphasis must be placed on addressing economic and social perspectives before humans can see the massive complex systems change necessary to solve future problems. Applying life principles (or bio-tradition) to investment leads to the reorganization of investment activity and its reintegration with the world.

Using these biomimicry principles in their investment may lead to greater clarity in decision-making, overall financial and non-financial returns, and joy. It does not provide any financial return data on its biomimicry investments. It will be interesting to see if these investments have shown any outperformance against the appropriate criteria.

The first principle is to be resource and energy efficient, with resource efficiency sub-principles including the use of multi-functional design and low-energy processes, the recycling of all materials, and the proper form of work.

Nature's second principle is to obtain non-toxic production, with sub-principles including selective construction with a small subset of elements. The third principle integrates development with growth, sub-principles combining normative and overlapping components, bottom-up construction, and self-regulation. Combining modular and overlapping components means growing in reproducible ways proportional to the organism's growth. The fourth principle is to be locally attuned and responsive, with the sub-principles of using readily available materials and energy, developing cooperative relationships, making use of cyclical processes, and using feedback loops. The fifth principle is an adaptation to changing conditions, with the sub-principles of maintaining integrity through self-renewal, The embodiment of flexibility through heterogeneity, redundancy, decentralization, and integration diversity. The sixth and final principle is an evolution for survival, with sub-principles that include repeating what works and incorporating the unexpected (Mark & Bhasin, 2014).

The history of sustainability science traces human-dominated ecosystems from the earliest civilizations to the present. This history is characterized by the increased regional success of a given society, followed by crises that have been resolved, production sustainability or not, resulting in extinction. The concept of sustainability moved towards nature in the late twentieth century, as this concept recognizes that human civilization is an integral component of the natural world, and that nature must remain and be sustained if human societies want to survive and thrive on planet Earth. Sustainable development is defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs. Nature has crystallized because of several definitions that put forward basic ideas about sustainable development, among which are preserving renewable resources, improving the quality of life, meeting the needs of future generations, achieving balance with the natural world, and creating integration between human society and the natural environment in which it lives. Natural ecosystems around human civilizations are constantly moving towards a steady state where less energy is required. There have been many theoretical propositions and international literature that sought to clarify the phenomenon of sustainability in various fields of knowledge, especially concerning architectural sustainability and how to create integration and compatibility between the building and the environment. The architectural literature indicated the role of the nature simulation strategy in generating a sustainable form with characteristics that affect the efficiency of the building and provide comfort to its users. Still, this phenomenon has not been studied in an applied manner. The expression that cities have a life of their own has a lot of validity, which is why mimicry of nature has become a very useful tool for the designer, clarifying the priorities for designing a community and sustainable buildings (Aanuoluwapo, 2017).

One impressive biological process is the climatic adaptability found in natural organisms. Fauna and Flora provide many examples of adapting to hot climates utilizing physical properties, behavioral interactions, or cooling processes. Besides these concepts, the natural skin plays an important role, as a thermo-adaptive layer, in regulating the body temperature of living organisms. When this concept is applied to the facades of buildings in hot climates, it means that the facades must be able to deal with the climate, especially natural ventilation, to act as an adaptive layer capable of cooling the interior spaces (Elgawaby, 2010). Designers dealt with nature in different ways, from future systems to ecosystem trends and then methods of self-adaptation. Nature teaches the designer to benefit from ecology in different ways. It must be remembered that nature has special laws that achieve its sustainability efficiently (Mwila et al., 2018).

Sustainability is a term with a holistic meaning, which is not limited to the narrow concept of reducing the consumption of natural resources necessary for the continuity of life on Earth. Still, it is an expression of achieving a suitable environment for humans that cannot continue without integration with the natural ecological systems. The integration of the Earth's natural systems with human patterns (sustainable design) is a relatively new design trend that appeared in its beginnings under the name green architecture, which focuses on the importance of the relationship and integration between buildings and nature and seeks integration and compatibility with the environment (Brian, 2001).

This chapter will collect the literature on climate change impacts on the built environment, international style, indigenous science, and biomimicry.

2.2.Climate Change Impacts on the Built Environment

Currently, nearly 50% of the world's population lives in cities, but this proportion is expected to rise to more than 60%t within the next 30 years. At-risk populations in many low-income countries are already exposed to a lack of clean drinking water and poor sanitation, often occupying high-risk areas such as floodplains and coastal areas (Haines et al., 2006). Due to the increasing concentration of urban residents and their assets, along with the increased risk of extreme events, the reinsurance industry suffers from high costs of weather-related losses (Berz, 1997). The scientific community is responding to these critical issues of human health and well-being through renewed interest in the basic processes that govern urban climates, as well as through research to improve weather forecasts and urban air quality (Souch and Grimmond, 2006). There has also been a growing desire by planners and architects to develop settlements and build homes that are more energy and water-efficient while at the same time reducing risks to human health and the environment (Mills, 2006). Others noted the significant contribution made by the world's major cities to global climate change, the urgent need for energy-efficient infrastructure, and the changing patterns of resource consumption (Hunt, 2004). With such a range of issues to be addressed, it is not surprising that there have been calls for broader participation and more effective interaction between complementary disciplines (Oke, 2006). Thus, it is recognized that urban areas are subject to regional climatic change and constitute an important component of it.

There is no doubt that the population, infrastructure, and environment of cities are at risk from the effects of climate change. Nevertheless, tools have become available to address some of the worst effects. For instance, appropriate building design and climate-sensitive planning, avoiding high-risk areas through stricter development control, including climate change allowances in engineering standards applicable to flood defenses and water supply systems, or allocating green spaces for urban cooling and flood attenuation. Citizens also have a responsibility to mitigate their collective impact on the local and global environment by reducing resource consumption and changing behavior towards a more sustainable lifestyle (Hunt, 2004).

Under some circumstances, adaptation and mitigation must be addressed within a broader development context (du Plessis, 2003). There are many impacts of climate change that are expected to shape the future character and functioning of urban systems. Several important knowledge gaps emerged; First, there is an ongoing need to improve preparedness and forecasting of climate hazards, such as extreme heat islands or episodes of air pollution, to protect human comfort and health. Long-range projections of the urban heat islands (UHI) will require better characterization of anthropogenic heat sources and land surface feedback on boundary layer climates. An urban heat island (UHI) is an urban area or metropolitan area that is warmer than the surrounding rural areas due to human activities. The temperature difference is usually greater at night than during the day and is more pronounced when the winds are weak. UHI is most noticeable during summer and winter (Fan and Sailor, 2005). Second, there is clearly a need to improve the representation of floods within cities, both at the local and at the city and watershed levels, also to move away from difficult engineering solutions to urban drainage problems. More research is needed on future changes in the co-occurrence of high tides, storms, and estuarine river flooding (Svensson and Jones, 2005).

Part of the answer to these concerns will be the broader availability of high-resolution scenarios (space and time) of precipitation, wind speeds, and heat waves. For example, building designers are beginning to use high-resolution weather data to design climate-sensitive buildings that maximize human comfort while minimizing energy requirements (Hacker et al., 2006). New modeling techniques will also be needed to fully exploit probabilistic information arising from climate change. But there may be new cost implications arising from using such data, depending on the level of risk and acceptable uncertainty in the resulting engineering design (e.g., reflected in the height of flood defense assets or reservoir capacity). Above all, there is an urgent need to translate awareness of the impacts of climate change into concrete adaptation measures at all levels of governance. The Primer for Municipal Water Providers (Miller and Yates, 2005) and the Checklist for Development (GLA, 2005) provide good examples of how the latest scientific understanding of sectoral impacts and adaptation responses can be shared with practitioners (Wilby Robert, 2007).

The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) sets out a strong case linking human emissions of greenhouse gases to climate change. Among the bold statements were the assertions that most of the global warming over the past 50 years was attributable to human activities; that human activities will continue to change the composition of the atmosphere; and that global mean temperature and sea levels will continue to rise for centuries to come (IPCC, 2001).

Climatologists have already begun to discover and attribute changes in extreme events to human influences on the global climate system (Zwiers and Zhang, 2003). For example, the risk of a heat wave such as the one across Europe in 2003 is believed to have been doubled by historical greenhouse gas emissions (Stott et al., 2004). Risks of other extreme events, such as intense precipitation, destructive tropical cyclones (Emanuel, 2005), and flooding (Milly et al., 2002), are also expected to increase. It is not surprising that managing current weather-related risks has become a major activity as evidenced by, for example, the increasing number of heat health warning systems in urban areas or measures to counteract excessive temperatures in urban centers through improved planning and building design (Shimoda, 2003). However, the range of potential effects is expected to exceed heat waves. Other expected consequences of climate change for cities include fewer periods of severe winter cold; increased frequency of episodes of air and water pollution; rising sea levels and an increased risk of storms; and changes in the timing, frequency, and severity of urban flooding associated with extreme precipitation events (IPCC, 2001). These changes, in turn, will have direct and indirect impacts on the environmental resources of urban communities (Wilby and Perry, 2006).

Detecting climate-driven trends across individual cities is problematic due to the high interannual variability of local weather and confounding factors such as land use change or urbanization effects. It has long been known that built-up areas can contain urban heat islands (UHI), which may be up to 5-6°C warmer than surrounding rural areas. Compared to planted roofs, building materials retain more solar energy during the day and have lower radiative cooling rates during the night. Urban areas also have lower wind speeds, less thermal heat loss, and evaporation, which results in more energy for surface heat. Industrial space heating, air conditioning, transportation, cooking, and industrial processes provide additional heat sources in the urban environment causing distinct weekly cycles at UHI intensity (Wilby, 2003). For recent reviews of urban climate research (Souch and Grimmond, 2006), the physical components of built-up areas and human activities within urban centers also interact with other climate drivers. For example, runoff from impermeable surfaces can have dramatic effects on downstream flood risk and erosion, as well as modulating river temperatures and water quality through uncontrolled stormwater discharge (Paul and Meyer, 2001). Urban air pollution concentrations may also increase during heat waves with significant consequences for mortality, as occurred in the summer of 2003 (Stedman, 2004). This is because high temperatures and solar radiation stimulate the production of photochemical smog as well as bio-volatile organic compounds (VOCs) by some plants (Wilby, 2007).

Climate change can be expected to lead to changes in climate and extreme weather. But it is difficult to associate a single extreme event with a specific cause, such as an increase in greenhouse gases, because a wide range of extreme events can occur even in an unchanging climate and because extreme events are usually caused by a combination of factors. In addition, climatic events, even if not statistically severe, can lead to extreme conditions or impacts, either by crossing a critical threshold in a social, ecological, or physical system or by co-occurring with other events. A weather system like a tropical cyclone can have a severe impact, depending on where and when it approaches land, even if the specific cyclone is not as severe as other tropical cyclones. On the contrary, not all extreme events necessarily lead to dangerous effects (Field et al., 2012).

Many climate extremes are caused by natural climatic fluctuations, and natural decadal or multidecadal changes in climate provide a background for anthropogenic climate changes. Even if there were no anthropogenic changes in climate, a variety of natural and extreme weather events would still occur (Nicholls et al., 2012).

Climate change leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather events and can lead to unprecedented extremes. Changes in extremes can also be directly related to changes in average climate because in some variables, future conditions are expected to lie in the tails of current conditions. However, changes in climate or weather variables do not always correlate simply with changes in the mean of the same variable, and in some cases, can be of opposite sign to the change in the average variable. Changes in phenomena can affect the frequency and intensity of extreme events in several regions simultaneously (IPCC, 2012).

2.3.Extreme Environments and Extremophiles

The history of life on Earth has been a series of evolutionary expansions of biodiversity that have been repeatedly reversed by minor or major geophysical disturbances. These disturbances arose either internally within the Earth (such as volcanoes) or externally (such as the effects of extraterrestrial bodies). Through direct and indirect climatic influences, these catastrophic events often devastated societies indiscriminately, with the result that the renewal of diversity began from the compositionally changed societies and took on new evolutionary directions (Marshall, 2015). Today's human activities are causing atmospheric carbon dioxide and global temperatures to increase at a rate unprecedented in recent geological history, with attendant shifts in precipitation patterns and species distribution. According to the Intergovernmental Panel on Climate Change (IPCC), the probability of extreme climate events associated with global warming is increasing (Drijfhout et al., 2015). This alerted ecologists to the potential for more frequent or severe disturbances to ecological communities due to droughts, storms, exceptional rains, heat waves, fires, and abrupt changes in ocean circulation.

Extreme weather events are becoming more common across planet Earth, and the increasing frequency with which extreme weather events occur is an issue of concern among architects. According to the latest report by the UN Office for Disaster Risk Reduction (UNDRR), rising global temperatures are mainly responsible for the significant increase in extreme weather events (UNDRR, 2020). Between 2000 and 2019, there have been 7,348 major natural disasters, killing over a million people and causing economic losses worth $2.97 trillion globally. In comparison, in the prior 20-year period (1980-1999), 4,212 natural disasters occurred worldwide, claiming about 1.2 million lives and causing economic losses worth $1.63 trillion (UNDRR, 2020). The same report further notes that comparing the two 20-year periods reveals that flooding more than doubled, severe storms increased by 40%, and heatwaves, wildfires, and droughts increased. A report by the European National Science Academies concurs that the frequency of extreme weather events has increased and urges national governments to formulate policies to adapt to and mitigate the causes of climate change (European Academies' Science Advisory Council, 2018). Such procedures could target economic sectors, such as the building and construction industry, contributing to climate change via Green House Gas (GHG) emissions.

The UN Secretary General's Special Representative for DRR stated in a statement that "we are willfully destructive" after the release of a report on climate change, revealing that human activity is primarily to blame for global warming and climate change. This statement shows an underlying problem; that is, humans prioritize their needs over those of other living things, harming the environment. Human activity in urban areas adversely affects the environment. Studies comparing rural and urban areas climates have found differences (Luca, 2017). Researchers have found that temperature is a significant factor that shapes the climate in these two areas (Popescu and Luca, 2017). Temperature is directly connected to human activity in the built environment in cities and is partly responsible for GHG emissions, global warming, and climate change (Popescu and Luca, 2017). Tall buildings in urban areas have glass that reflects and concentrates sunlight. They also have concrete that absorbs the sun's energy, heats up, and re-radiates the energy, warming up the surrounding environment. The rising temperature of the surrounding environments harms nature and potentially upsets ecosystems and natural ecological balances. Despite the harmful effects of the built environment, many regions worldwide retain the concrete-and-glass elements of the International Style.

Extreme events in time may be associated with extremes in space. For example, organisms encounter limits to their physiological tolerance of water, heat, or chemical environment when they enter new environments at or outside their normal geographic boundaries and subsequently undergo strong selection (Conte et al., 2012). Environmental conditions at the margins of geographical distributions are likely to be extreme - which is why such sites are often margins (Lachapelle et al., 2015). Daily, seasonal, or annual fluctuations in limiting factors in such environments place strong evolutionary pressures on frontier organisms. It is expected that these pressures will increase in the future at some borders and decrease at others (Seabrook et al., 2014).

How organisms respond to extreme environmental conditions depends in part on their behavior, previous exposure to extreme events, their phenotypic diversity, the degree of genetic variation in traits related to fitness, demographic factors such as age and dispersal (gene flow), as well as the magnitude of deviations from the mean Environmental conditions and how long these conditions persist concerning the lifespan of living organisms (Chevin, 2017).

Ecologists, especially those interested in ecophysiology or, at the ecosystem level, the effects of unusual weather on plants, combine events and responses into a single definition of extreme events (Smith, 2011). This has the advantage of avoiding many instances of natural responses to unusual events. Furthermore, operational definitions are invaluable for comparison purposes. Our job is to identify or predict any evolutionary response to an extreme event. This general concept, as explained above, is more useful than a precise definition. In the future, extreme events can be defined as events whose magnitudes exceed 95 percent of long-term measurements (Grant et al., 2017). This begs the need to look at extremophiles, the type of species that can adapt and thrive in extreme biological conditions.

Nature is the first teacher; it is a self-regulating, self-adapting, self-correcting organism. Nature also has its laws and principles for preserving the ecosystem (Arosha et al., 2012). Nature is the source of systems, materials, processes, structures, and aesthetics, and the capabilities of nature in many areas are superior to the capabilities of human beings. Through it, it is possible to derive appropriate design solutions for some problems at the right time, and new directions for our built environments can be explored (Ashraf, 2011) as the design thought that combines biology and architecture to achieve the complete unity between the building and nature (Michael, 2014).

Biomimicry is considered an inexhaustible source for bio-simulating new energies to reach sustainable design technology. In various fields, such as architecture, interior architecture, and furniture, through a new science that depends on the intersection of various fields of design, such as architecture, urban design, engineering, and designs, with basic sciences, such as biology, chemistry, and mathematics, with the discovery of areas of cooperation and exchange of sciences inspired by the simulation of nature (Abouelela, 2014).

2.4.Nature and Design

Nature has occurred in various design aspects through time. Biophilia believes that design supports the inherent desire of humans to “join natural systems and processes” (Kellert 2008). The terms “biomorphic” and “organic” have been used in design since the 1930s and relate to natural processes (Wunsche 2003). An approach that integrates environmental processes to minimize environmentally destructive impacts is called ecological design (Van der Ryn and Cowan 1996).

Van der Ryn and Cowan (1996) pointed out that incorporating nature into design is nothing new. What was often missing in the early efforts of the late nineteenth century was a consideration of all species and a systematic approach to addressing the implications of human design efforts on ecosystems. Moreover, Van der Ryn and Cowan (1996) believe that the 1960s gave rise to the first modern generation of environmental design, while future models would require interdisciplinary efforts. Van der Ryn and Cowan (1996) also suggest that design adheres to the following principles: solutions grow out of place; Environmental accounting informs design; Design with Nature, everyone is a designer, and make nature visible. Eugene Tsui (1999) believes that efficiency is as fundamental to design as nature is. "Living technology" combines nature and human creativity to have an interrelationship to the point that nature will drive industry and the economy (Tsui 1999). To bring efficiency into his designs, he attempts to extrapolate from a set of principles, though it is difficult to claim that efficiency alone is nature's ultimate goal. Evolution suggests that random mutations are responsible for modern designs (innovation) and that successful designs manifest through subsequent generations (specialized discovery) (Orr 1998). Therefore, Tsui's creation of principles is a way to achieve a common language between design and nature consistent with Yeang's philosophy.

Ledewitz (1985) presents a complex intellectual activity model that allows the individual to "break down the problem into a series of structural relationships, which are reorganized by reformulating the problem" (Milburn & Brown 2003). Establishing selection criteria at the conceptual stage is not intentional, as was the case with the concept testing model. Eugene Tsui (1999) suggests that challenges in design, like nature, include: finding suitable structural systems, searching for construction means that save time and labor, and the amount of time required to conduct additional research. Within this design process, the effects and relative success after construction are evaluated and documented to inform future design endeavors (feedback loop) (Albertson, 2010).

2.5.Vernacular Architecture

Vernacular architecture is the building style of indigenous people. It is an architectural style designed based on local needs, the availability of building materials, and a reflection of local traditions. Vernacular architecture builders did not have any formal architecture teaching but relied on the design skills and traditions of local builders. Nevertheless, since the late 19th century, many professional architects have worked this way. Vernacular architecture can be compared with architecture characterized by stylistic elements of deliberate design for aesthetic purposes that go beyond the functional requirements of the building (Jo et al., 2019).

Vernacular architecture is architecture characterized by the use of local materials and knowledge, usually without the supervision of professional architects. Vernacular architecture represents the majority of buildings and a settlement created in pre-industrial societies and includes a wide variety of buildings, building traditions, and construction methods. Vernacular buildings are usually simple and functional, whether they are residential homes or built for other purposes. Although it comprised 95% of the world's-built environment in 1969, vernacular architecture tends to be overlooked in traditional design histories. It's not one specific style, so it can't be broken down into a series of easy-to-understand patterns, materials, or elements. Due to traditional building methods and builders, local buildings are considered part of the regional culture. (Li, Mengbi et al., 2020).

Vernacular architecture is influenced by a wide range of different aspects of human behavior and the environment, resulting in different building forms for nearly every different context; even neighboring villages may have different approaches to the construction and use of their dwellings, even if they seem similar at first. Despite these differences, each building is subject to the same laws of physics and thus will show great similarities in structural forms. One of the most important influences on vernacular architecture is the overall climate of the area in which the building is being constructed. Buildings in cold climates almost always have a high thermal mass or a large amount of insulation. They are usually closed to prevent heat loss, and openings such as windows tend to be small or non-existent. By contrast, buildings in warmer climates tend to be constructed of lighter materials and allow significant transverse ventilation through openings in the building fabric (Keniger et al., 2013).

Buildings for a continental climate must be able to handle large temperature changes and can even be changed by their occupants according to the seasons. In hot arid, and semi-arid regions, vernacular structures typically include several distinct elements to provide ventilation and temperature control. Buildings take different shapes depending on the region's precipitation levels

- resulting in dwellings on stilts in many areas with frequent flood seasons or monsoon rains. Climatic influences on vernacular architecture are significant and can be very complex (Li, Mengbi et al., 2020).

As a permanent built form, vernacular architecture and settlements show a deep connection to the natural environment and other forms of life (Knapp, 1992). Moreover, the residents' strong attachment to nature in their daily lives and their residence in largely self-constructed buildings introduce interesting features that resonate with the concept of biophilia. In vernacular architecture and settlements, research in the field of dynamic design has the potential to advance studies in architecture and vernacular settlements. Recent research in this area provides a systematic explanation for why people need to maintain their connection to nature through the built environment (Heerwagen, 2006), particularly through patterns or traits (Jo et al., 2019), (Keniger et al., 2013, Ryan et al., 2014). These investigations provided an important reference to better understand vernacular architecture and settlements. First, this study offers a new perspective for observing the relationship between indigenous cultures, the regional natural environment, and the corresponding vernacular morphology of buildings and settlements. Second, the bio-design concept is not only a path to a better understanding of the local built environment but also a channel for the disclosure of knowledge and practices accumulated through experience and practical application, especially of humans' innate affiliation with nature and natural elements (Ramzy, 2015). On the other hand, studies in architecture and vernacular settlements may offer some lessons for biophilic design. It may also serve as a sounding board for local people and traditions to support further explorations into bio-design and the interrelationship between urban sustainability and bio-city (Yigitcanlar et al., 2019).

Energy shortages and rising energy consumption in homes have been significant issues globally since 1970. There is a growing need for interventions that will help promote using alternative energy in the built environment. Meanwhile, nature-inspired styles emerged as a new approach to achieving indoor thermal comfort. Nevertheless, to apply these strategies in the design and development of the built environment, one must have a good understanding of the ecosystem. The way biological systems solve problems is very different from how engineered systems solve problems, and human-designed solutions are both primitive and additive. They are more dependent on resources and energy to speed up costly reactions. Nevertheless, natural procedures depend on the distinctive design and material properties (Srinivsan, &Madhumathi, 2020).

Over the centuries, nature has changed and acquired incredibly advanced strategies for overcoming major issues. The environment around us provides good examples of functional structures made from a limited number of materials. Many of these strategies can impact people to achieve exceptional results. The design of fishing nets, for example, may have been derived from a spider web, and the lightweight structures used in aircraft and other structures may have originated from the sturdiness and stability of honeycombs (Olugbenga et al., 2013). While modern sustainable research has become prominent over the years, the idea existed long before. People have been drawing inspiration from nature for new materials and inventions ever since the Chinese tried to make fabric more than 3,000 years ago. The practical use of nature simulation is now recognized as a feasible strategy to help solve environmental problems.

Roughly speaking, in the second half of the twentieth century, mankind realized the limits of comprehensive development based on the Industrial Revolution and the many environmental risks associated with it. The search for new approaches that harmonize humans with the environment has become a priority. Indigenous cultures, much like extremophiles, have a responsible vision of the world in harmony with a sustainable environment.

2.6.Historical Background of Biomimicry

In light of what the world is facing, the shortage of resources and the weather changes that resulted from the misuse and exploitation of natural resources and the impact of humans' current lifestyles on the environment lead us to deplete the natural resources of the earth. The way to address this situation is either by preserving natural resources or biomimicry, which is sustainable by its nature by taking nature as a model and measure and the process of mimicking or biomimicry, also known as *Biomimetic* or biologically inspired designs as a tool and strategy for achieving sustainability, involves finding solutions to design problems by looking at nature for inspiration.

The study of birds that helped humans get to the invention of flight was one of the first examples of mimicry of nature. Leonardo da Vinci, Frank Lloyd Wright, Frei Otto, and Antonio Gaudi are examples of early practitioners of mimicry. Nature has provided tremendous ideas and inspiration for architectural designers. Dina Baumeister, a professor at Arizona State University and co-author of the book Biomimicry, explained the concept that nature has solved many of the problems we face today and how this can be used in design. Through analysis, these designs can be simulated by the three levels of biomimetic engineers. To understand nature's design, we must understand the three levels of biomimicry: nature as a model, nature as a scale, and nature as a guide. In 1982, Otto Schmidt coined the word biomimicry, and in 1997, Janine Benyus, innovation consultant and co-founder of the Nature Mimicry Institute, rediscovered the word. The idea of mimicry of nature is sometimes misinterpreted as structures that appear as natural organisms, that is, shell-shaped structures. This is another distinctive strategy in the design called Biomorphology (Nosonovsky, 2018).

Imitating natural structures or styles will affect the form, but this is not the basic concept of mimicry. Therefore, biomimetics is not a direct imitation of nature, neither in matter and function nor technically, but an understanding of the principles of nature to help understand similar technological issues that can then be resolved by implementing integrated technologies. The architect has abundant living nature to discover, but one must be careful not to interpret it directly. Nature's inspiration for architecture will not succeed if the architects do not follow the intermediate stage of abstraction. The application of biomimetics is a 3-step process: search, abstraction, and implementation. Initially, the design method is based on the understanding of biologists and scientists rather than human design issues. The designer identifies a relevant environment feature that is abstracted before it is identified and transformed into a technological context. Srinivsan's study of biomimetics shows that it is one of the tools of sustainable design. Srinivsan and Madhumathi believe that feedback schemes in nature for the design method are closely related to and influenced by the environment and are more sophisticated in terms of environmental and sustainable outcomes (Srinivsan &Madhumathi, 2020). The design method has two categories of biomimetics: identifying a need or design problem for humans and figuring out how other organisms or ecosystems solve that problem (SabryAziz, 2016).

In adapting to biomimicry in the building form, innovative products, or real developments in the form of "truly biomimetic" buildings are still lacking" (Badarnah, 2017). This means that biomimicry can be viewed as architectural patterns that define the entire building that is best reflected In its general form (Srinivsan &Madhumathi, 2020).

2.7.Biomimetic Levels

McDonough and Braungart believe biomimicry as a design approach offers a solution for a more ecological, sustainable, and regenerative built environment. According to Baumeister

(2014), only when the three levels of biomimicry (organism, behavior, and ecosystem) are considered does the design “behave like a well-adapted organism” and “create conditions favorable to life.” (Nkandu & Alibaba, 2018)

The information embedded in each organism can be found at many levels. The potential features inferred from the organism and its biomimicry are analyzed using three levels. Each level is concerned with a layer of organism design. The first comprises the aspects and characteristics of the feature as a complete unit. The second comprises other features that focus on the relationships between an organism and its living community. The third level highlights electronic systems and solutions that can be inferred from the relationships between an organism and its context/environment. Within each of these levels, there are five other possible dimensions of imitation. A design may be biologically imitative, for example, in terms of how it works (process) or what it can do (function), what it is made of (material), how it is made (construction), and what it looks like (form). M. Pedersen Zari attempted to explain the dissimilar levels and dimensions of biomimicry and proposed a framework for understanding its application. This applies to both approaches: biology looks at design, and design looks at biology (Khelil, 2015).

2.7.1. Natural Form/ Organism Level

Copying the natural form of an organism or a species is the first level of mimicry. Using the specie’s shape does not automatically make the design sustainable, as it would need to involve a deeper level to achieve biomimetic principles.

An organism-level approach may help to understand the negative environmental impact of human activities on the world and many of its ecosystems. For billions of years, living things have withstood and adapted to many changes. Therefore, humans have a variety of examples to study and plot solutions to problems already addressed, particularly in the efficient use of energy and materials. As Baumeister (2007) points out, "the research has already been done". (Alberti et al. 2003) A disadvantage of living organism mimicry is that without mimicking how it interacts and contributes to the ecosystem in a larger context, it has the potential to produce designs that are below average in terms of the effect it will have on the environment (Nkandu & Alibaba, 2018).

2.7.2. Natural Process/ Behavior Level

The behavioral level depends on how the thing is made and the fact that many organisms have learned to function within the capacity of specific environmental conditions and the limits of availability of energy and materials; they experience the same environmental conditions as humans and therefore need to solve similar issues that humans face. These limits, as well as the pressures that create specialized ecological adaptations in ecosystems, imply not only those well-adapted organisms continue to evolve but that all organisms' behaviors and patterns of well-adapted relationships between organisms or species (Nkandu & Alibaba, 2018).

2.7.3. Natural Ecosystem/ Ecosystem Level

Benyus (1997) and Vincent (2007) describe ecosystem simulation as an integral part of nature simulation. An advantage of mimicry at this level of biomimicry is that it can be used in conjunction with other levels of biomimicry (organism and behavior). However, the most important advantage of such an approach to biomimetic design may be the potential positive effects on overall environmental performance (Nkandu & Alibaba, 2018).

2.8.Principles of Biomimetics

Michael Pawlyn has used biomimetics to find design solutions for efficient structures, materials manufacturing, zero-waste systems, water management, thermal environment control, and energy production. One of Pawlyn's most famous designs is the Desert Forest Project. In addition to using biomimetics to find design solutions, Biomimicry has also been commonly used for aesthetic purposes, for example, TWA Terminal, by Eero Saarinen, at John F Kennedy Airport in New York. In this example, no purpose or solution is provided by designing the buildings' wing-like shape; it is merely a representation of aviation. Another example is the columns in Frank Lloyd Wright's Johnson Wax Building, which bear the appearance of water lilies but have no purpose other than to present a different perspective of space design.

From the studies discussed earlier, there is a greater amount of knowledge available, other than typical technological problems, for improvements to building envelopes, heating, cooling, and site development that can be developed into designs (Khelil, 2015). Within all these levels, the potential for biomimetic design may depend on certain aspects like; how it looks in shape, what materials it is made of, how it is constructed, how the work process is done, or what it can do in business. In a way, there is an overlap between the different levels of biomimetics that exist. For example, a system capable of interacting as an ecosystem would operate at the ecosystem level of a nature-mimicking process. Pederson Zari (2007) explained a set of principles derived from a disciplinary understanding of ecosystem functions of principles in biomimetics to model system functions and analysis in electronics, biology, industrial ecology, and biomimetics. Designers such as architects and engineers in the field can comply to help develop methodologies to enable the creation of a sustainable built environment that will serve the entire world. Zari's (2012) research shows that ecosystem principles depend on the complexities of certain aspects of ecosystems with several controversial theories in ecology, such as the exact and mechanical process in the succession of ecological principles. According to previous research, the principles of an ecosystem are (Khelil, 2015):

1. Ecosystems depend on temporary sunlight.
2. Ecosystems improve the system rather than its components.
3. Ecosystems are compatible with and depend on local conditions.
4. Ecosystems are diverse in terms of components, relationships, and information.
5. Ecosystems create favorable conditions for the sustainability of life.
6. Ecosystems adapt and evolve at different levels and different rates. Continuous flow balances the imbalance.

Therefore, the principles of biomimetics can be summarized as follows (Button, 2016):

- Preserving the natural environment.
- Simulating nature and interacting with the surrounding environment.
- Energy conservation and use of renewable energy.
- Reducing the consumption of non-renewable resources and preventing the use of toxic substances.

Building in a way that mimics nature based on these principles is defined as building practices that seek integrated quality (economic - social - environmental) in sound and clear ways. The rational use of natural resources and the appropriate management of buildings contribute to saving scarce resources, reducing energy consumption, and improving the environment and environmental quality while achieving functionality and aesthetics (Khelil, 2015).

2.9.Biomimicry and Indigenous Cultures

Most human beings have lost a vital connection to the natural world - a connection that, from the inception of the human race until recently, was aware of and continued to participate in nature. Scientific and industrial revolutions brought near-miraculous technical progress and solved many problems, but they also spread a mindset in which progress meant replacing the old with the new. Humans have come to prefer broadly applicable technological solutions over vital place-based cultural wisdom and the value of short-term gratification over the art of long vision. Eventually, they came to think of the psyche and culture as somewhat separate from, or even independent of, nature. With 7.4 billion people facing a common fate of dangerous climate change, environmental degradation, and depletion of non-renewable resources, they are finally beginning to care about the scientific truth that they are living beings. The cultures they co-create are emerging properties - phenomenology - of life and nature. Humans are intricately intertwined with the biological and geophysical processes that sustain life on Earth. The common future of humans depends critically on understanding the central lesson of mimicry. Janine Benyus puts this golden rule of regenerative cultures succinctly and clearly: "Life creates conditions favorable to life." Taking this insight into account means nothing less than accepting the challenge of “redesigning human existence on Earth,” as David Orr put it (Sabrine, 2020).

Humans need to collaborate globally, regionally, and locally on an unprecedented scale to create “elegant solutions carefully adapted to the uniqueness of place” (John Todd). To do this, humans need to do more than just learn from nature, they need to design as nature, and that means changing human impact on Earth from being mostly degenerative to being regenerative. Simply designing for sustainability is no longer enough; humans must design for innovation. Learning from indigenous traditional wisdom - or traditional environmental knowledge (TEK) - is an important aspect of mimicry. Once the false duality and mental separation between nature and culture are overcome, humans can fully face the challenge of redesigning human existence on Earth. Among the many lessons humans can learn from indigenous cultures around the world; realizing that the world is alive and purposeful and that the relationship to the rest of life is one of sharing, communication, and co-creation, the practice of accessing the collective intelligence of the community through communication methods that involve deep listening and participation from the heart in the council circle, and the insight that the rest of the natural world is in constant communication (Nosonovsky, 2018).

Humans are increasingly looking to nature for inspiration to solve difficult problems. This is usually called biomimicry and is about the study of living systems to see how nature solved problems in the past that humans care about today. Much of the work in biomimicry is based on a subtle confusion - treating the "human world" as separate and distinct from the rest of nature because humans are somehow supposed to be separate from it. The truth is that humans are part of nature. This profound truth is poised to greatly extend the meaning of bio-tradition to include all human cultures, the techniques and patterns of social organization, and the solutions they have gathered throughout their long history as a species (Daniel, 2016).

Built environment designers must draw inspiration from nature not only for innovations in materials and construction methods but also in the design of space and building functions for sustainable and comfortable future environments (Nosonovsky, 2018).

Innovations and developments in information technology and computing are causing unprecedented changes in architectural design and construction. They appear in transforming design processes, procedures, delivery methods, manufacturing, and construction methods. These new ways of using digital tools to design can be more challenging than traditional 3D modeling software applications, but they allow for advanced model exploration. As rapid developments in digital technologies continue to make computers and computing essential in today's professional world, architectural practices must include new technologies and design approaches. The transformation of architectural design has begun, and it should be noted that the transformation of the paradigm affects not only architectural design outcomes and products (building forms, geometry, and volumes) but also design processes, including building information modeling, integration of simulation tools, performance analysis, processes and digital fabrication (Sabrine, 2020).

The definition of life and the difference between animate and inanimate nature has been among the major issues of the philosophy of science for centuries; nevertheless, a precise definition remains elusive (Tsokolov, 2009). Most modern definitions of life are descriptive, meaning that organisms are characterized by traits such as homeostasis, reproduction, regulation, metabolism, growth, adaptation, and response to stimuli (McKay, 2004). Nevertheless, besides scientific definitions, there are conceptions of what constitutes living and nonliving things. These perceptions are culture specific. The emergence of biomimetics affects the perception of living and engineered organisms as two separate worlds since biomimicry is similar to living things. There has been significant growth in interest in biomimetics in materials science and other fields of engineering in the past decade. Biomimetic materials and devices mimic living nature, including living organisms and plants, or at least such materials and devices are inspired by living things or borrow certain design characteristics or methods from nature. There are significant differences between traditional engineering design approaches and those inspired by nature. Engineers usually have blueprints for their end product, which often use traditional engineering materials such as metals, which require high temperatures and pressures to produce. In contrast, nature uses composite materials and hierarchically organized structures. Organisms in nature are usually developed through self-organization with adaptation to changing environmental conditions without a blueprint for the result but using hierarchical organization and iterative DNA algorithms. Biomimetic design must borrow some of these approaches from nature. For example, in materials engineering, this could mean more emphasis on composites, nanostructured materials, hierarchically engineered materials, metamaterials, and the like rather than on selecting traditional engineering materials (Koshland, 2002).

The emergence and spread of biomimetics, i.e., simulating living nature for engineering applications, has affected how the difference between natural and artificial is perceived. Although engineering biomimetic devices, materials, and systems are certainly not living organisms, they can mimic some properties of the latter, including self-assembly, self-repair, self-replication, and adaptation more general shift in paradigm, which must be viewed in the context of the social and ideological implications of mimicry concerning the relationship between man and nature. From the nineteenth century until the mid-20th century, the dominant human attitude toward nature was the belief that science and technology would eventually provide an almost unlimited power to conquer and transform nature in a convenient way for humans (Tsokolov, 2009).

Effective restoration of the natural environment; nevertheless, in the second half of the twentieth century, it became clear that it was impossible to solve many economic and social problems by simply trying to conquer nature. The relationship between man and nature is more complex, and humans can benefit from learning from living nature rather than trying to change it. As a result, new fields such as "environment" and "holism", emphasizing the harmony between humans and nature, are becoming increasingly popular. The emergence of biomimicry is part of this trend. An interesting aspect of biomimetics is that technological progress and environmental protection are feasible, at least in theory, although they need to be demonstrated through better practices (Nosonovsky, 2018).

2.10. Design Approaches to Biomimicry in Architecture

Sustainable development has often been criticized as ambiguous as a fundamental principle of the built environment (Roseland 2005). Other obstacles in planning, designing, and constructing the built environment include design approaches that lack feedback loops (Van Bueren 2007) and a lack of a common language for multiple disciplines to assess built and natural environmental impacts (Brandon et al., 1997). The emerging field of biomimicry suggests that nature provides functions, strategies, and properties within a set of principles that function as design blueprints and lay the foundation for all life to survive and thrive on Earth (Benyus 1997). Biomimetic guild theory posits the incorporation of these principles, called Principles of Life (LPs), which increase the likelihood that the design in question will be sustainable and increase the likelihood that the design will have a greater impact on sustainability for future generations of all kinds (Benyus 1997). Since the 1960s, linear thinking in the construction industry has attempted to control environmental variables through design by limiting and controlling environmental resources (Van Bueren 2007). However, a paradigm shift from linear to systems thinking has occurred in recent decades to recognize the environment as a dynamic system that acts according to arrows, flows, feedback, and thresholds (Van Bueren, 2007). This is important because populations and ecosystems influence the design of the built environment due to many factors, including resource depletion, climate change, and continued global population growth both locally and on a larger scale (Yanarella, 2009).

Sustainable building practices have been used at the local, regional, national, and international levels. They include the establishment of environmentally responsible standards, the use of 'green products, and the conduct of life cycle assessments (Van Bueren 2007). Nevertheless, an enormous amount of research needs to be done for the built environment to be resource efficient and economically sustainable, as previous sustainable building efforts have been welcomed to varying degrees by industry, and factors such as climate change appear to be more serious than previously anticipated (Van Bueren 2007; Van den Berg 2007). Bio tradition seeks to expand thinking about sustainable building systems and practices through "principles" that include similar terms such as taking advantage of interdependence, integrating cyclical processes, and using life-friendly materials (Albertson, 2010).

After more than three billion years of research, nature has already evolved and solved many of its problems. Animals, plants, and other living organisms have designed themselves to survive and thrive without producing any waste and are very resource efficient. Therefore, simulating nature's forms, systems and processes provides an opportunity to maximize resource efficiency while mitigating the negative impact of buildings on the environment (Benyus. 1997).

Biomimicry is the simulation or imitation of nature in its many forms, systems, and processes to solve the most pressing challenges our world faces today. So far, mimicry methods have improved sustainability and efficiency, especially in design and construction. Nevertheless, this increasingly prominent approach has led to the development of various other fields, such as aerodynamics, robotic navigation, medicine, clothing design, and water pollution detection (Michael Pawlyn, 2011). Early examples of Biomimicry are seen in Leonardo da Vinci's drawings of a flying machine inspired by the wings of a bat. Another example comes from Fillipo Brunelleschi, who studied the power of eggshells and designed a thinner, lighter dome for the cathedral in Florence in 1436 (Bar-Cohen, 2012).

In 1809, naval architect Sir George Kelly designed more streamlined ship hulls by studying dolphins. A more famous example occurred in 1948 when Georges de Mestral, a Swiss engineer, took his hunting dog and emerged from bushes covered in burrs. After examining the small hooks of the blades, he discovered the hook system the plant uses to spread seeds through a link. Inspired by this, De Mestral created Velcro. Throughout history, architects have been inspired by nature solely to build shapes and aesthetics. However, biomimetics in architecture is an applied science that not only buys the aesthetics component into nature but also takes lessons from nature to solve problems in a building's functionality. An interdisciplinary approach follows a set of ethics rather than a stylistic approach (Nkandu & Alibaba, 2018).

Sustainability advances to a new level embracing the design of buildings that are essential to the natural environment and must support the action of nature rather than work against it. It has gained popularity in the past ten years for solving sustainability issues while minimizing the negative impact on nature (Pedersen, 2005). There are three goals to reach the so-called "ecological age" by 2050, and they include; "Reduce CO2 emissions by 80%, reduce the ecological footprint to 1.44ga/person and further improve the HDI." It is the responsibility of architects to develop optimal environmental approaches to design, construction, and performance. This includes incorporating natural ecosystems into their designs while considering patterns of human behavior (Nkandu & Alibaba, 2018).

According to the examination by M. Pedersen Zari at Victoria University of New Zealand in 2007, there are two distinct approaches to nature imitation as a design approach: the problem-based approach and the solution-based approach. Each approach has its advantages, disadvantages, and outcomes regarding overall sustainability. The problem-based approach has been found variously labeled in various pieces of literature such as "Design Researches Biology" (Pedersen

Zari, 2007), "Biologically-Driven Problem Inspired Design" (Michael Helms, Swaroop S. Vattam and Ashok K. Goel, 2009) and "Top-Down Approach" (Jean Knippers, 2009) all have the same meaning. In this approach, designers look to nature in search of solutions. Where the designer learns about his design problem and considers how objects and systems in nature solve similar problems. One potential drawback of this design approach is that the question of how buildings relate to each other and the ecosystem of which they are a part has not been investigated. Therefore, the underlying causes of an unsustainable or degraded built environment are not necessarily addressed. Despite this, a problem-based approach may be an effective way to start the transition from the built environment as a passive environment to a more sustainable and responsive environment (McDonough., 2002).

The solution-based approach is also referred to as "biological impact design," "bottom-up approach," or "biologically inspired design." In this approach, biological knowledge influences human design (El Ahmar, 2014) . One advantage of this approach is that knowledge of biology may influence design in ways other than a predetermined design problem. One drawback is that in-depth biological research must be conducted, and the information collected must be identified as relevant in the design context. (Pedersen Zire, AD 2007).

After examination by Janine Benyus in her 1997 book entitled "Biomimicry: Innovation Inspired by Nature", the methods discussed above fall into three levels of imitation, namely, Form (organism), process (behavior), and ecosystem. These levels help identify the types of biomimetics that have evolved. They provide a framework for designers who wish to use mimicry of nature to improve the sustainability of the built environment to determine which approach to take. This will help designers decide which aspect of 'liveliness' to 'copy' (Pedersen Zari, M. 2007). The designed organism level entails looking at what a particular organism looks like and analyzing how it functions; the designer can choose to imitate a part or the entire object.

2.11. Biomimicry and Architecture

At the end of the twentieth century and the beginning of the twenty-first century, a group of architectural trends emerged trying to conform with the variables of the natural environment to achieve sustainability. The most important of these trends is the trend of simulating nature, which achieves the concept of sustainable development as defined by the World Commission on Environment and Development in 1987, which is to obtain the needs of the present without compromising on the right of the future generation to find their needs. This definition refers to two very important elements; First: Legalization of rights: the right of the present generation to obtain its requirements without infringing the rights of future generations. Second: Preserving the environment: i.e., the ability of the environment to meet the needs of the present and the future (Pawlyn, 2011). There are many goals to simulate living natural systems, including (Pohl & Nachtigall, 2015):

1. Significantly increase the efficiency of resource use.
2. Changing the consumption curve from linear to annular to reduce the resulting pollution
3. Shifting from a fossil fuel economy to a solar energy economy

Biomimetic architecture is a contemporary philosophy that seeks solutions for sustainability in nature, not through the repetition of natural forms but through an understanding of the rules that govern those forms. It is an interdisciplinary approach to sustainable design that follows principles rather than stylistic codes. It is part of a larger movement known as bio biology, which examines nature and its models and systems. Biomimetics not only helps discover new and sustainable solutions in architecture but can also be implemented in other ways to help human needs (Button, 2016).

Architects and designers have looked to nature for inspiration since the beginning of science in the early 19th century. They sought not only to imitate the shapes of plants and animals but to find design methods like the processes of growth and development in nature. Biological ideas are prominent in the writings of many modern architects, of which Le Corbusier and Frank Lloyd Wright are only the most famous. Le Corbusier declared biomimicry a new word in architecture and planning (Pohl & Nachtigall, 2015).

Bio architecture uses nature as a model and measure for solving problems in architecture. It is not the same as biomorphic architecture, which uses existing natural elements as inspiration for the aesthetic components of the form. Instead, biomimicry looks to nature as a model to imitate or draw inspiration from natural designs and processes and apply them to human designs. Using nature as a yardstick means using biometrics as an environmental criterion for judging the efficiency of human innovations. Nature as a mentor means that biomimicry does not attempt to exploit nature by extracting physical materials from it but rather values nature as humans can learn it (Abouelela, 2014).

Sustainable design is a leading practice in today's society for services, consumer goods, and more in response to overwhelming evidence pointing to global climate change. The built environment is at the forefront of the debate on reducing the environmental impact on the Earth and its inhabitants. To reduce the impact of the built environment, great effort is being made to change the way it is designed and constructed. This effort ranges from designing to maximize efficiency, using materials of choice, to changing building practices to minimize the impact on the environment. There are technology-based solutions to maximize construction efficiency. There are passive solutions to reduce the cost and impact of technologies by using more natural methods to allow nature to do the work. There is also an approach to using innovative natural methods that mimic the environment to reduce negative environmental impacts (Button, 2016).

These approaches can be found under a broad definition of ecological architecture, which is designed with the environment in mind by incorporating it into the design, as well as preventing harm to the environment through design and alternative energy strategies. However, each of these styles can be completely different and can have its kind of architecture. Nature and the environment can provide optimal solutions for the way the built environment is designed; it has had 3.8 billion years to evolve and figure out what works as well as to improve its performance (Benyus, 1997).

People involved in the built environment must focus more on past successes in nature and the environment to identify design solutions that will minimize their impacts. These design solutions are delivered through an approach known as biomimicry. However, the definition is still confused or unknown by people outside the fields of science related to biology. There is a consensus that biomimicry is the idea of using actual nature in design, and there is an argument by others, particularly in fields of science, that biomimicry is just the idea of using the natural design of nature and the environment to inspire our design. An accepted definition of mimicry of nature by those who study and use it is the concept of biomimicry, not necessarily using nature in design but instead using it as a study model for design in an attempt to simulate it (Pawlyn, 2011).

After acknowledging this biomimicry definition, designers, manufacturers, and others can conclude that it has already been in practice for some time in the design of the built environment and is still in development. This conclusion can be made based on using sites and landscapes to create climate-controlled zones for designs by simulating nature's climate to create microclimates beneficial to the building design and its users. Biomimicry can also be seen in how to deal with gray water. More natural methods can clean water by creating systems that use stones, plants, and bacteria to filter and clean the water rather than sewage systems and treatment plants. These serve as great examples of the benefits that can come from design through biomimicry (Button, 2016).

Global organizations such as the European Union (EU), the International Energy Agency (IEA), and the International Renewable Energy Agency (IRENA) have invested significant efforts in studying energy alternatives to reduce global energy consumption from fossil fuels and promote investment in renewable energy, along with more rational consumption before society (International Energy Agency, 2010; Austin et al., 2020)

Biomimicry, although very impactful in disciplines such as agriculture, construction, energy, fashion, food waste, material chemistry, sanitation, transportation, and architecture, it has not yet been used in sustainable architecture in the necessity the world currently demands and not specifically in extreme environments on a planet that is rapidly becoming extreme. Following the hypothesis by Edward O. Wilson, which he calls The Biophilia Hypothesis, humans constantly seek connection with the living world (Clowney, 2013). Biophilic design as a holistic approach would be the translation of correctly designed biomimetic architecture. The human need to connect with nature will provide designers and architects with the drive to seek inspiration from nature to solve design problems facing the contemporary built environment. There is a rising need for humans to return to their peaceful holistic way of living and learn from the indigenous people who understood the environment because they had a strong bond with their surroundings (Pohl & Nachtigall, 2015).

Architecture, because of its direct and indirect effects on the environment and natural resources, bears a great burden in defining the features of life on the planet, as sustainable architecture has become part of the world's sustainability system. John Ruskin stresses the need for development based on the same principle of homogeneity that governs nature, which Morris William calls to return to and live in rural areas where self-sufficiency and the revival of local skills. As for Lethaby Richard, he drew the architects' attention to nature, calling for the exploration of its beauty and harmony. Mcharg Ian stresses that nature has systems and patterns of cooperation that can benefit from design (Button, 2016).

Biomimicry aims to significantly increase the efficiency of resource use, change the consumption curve from linear to annular to reduce the resulting pollution, and shift from a fossil fuel economy to a solar energy economy (Williams, 2007). In recent years, biomimetics has become relevant to engineering and architecture, giving way to buildings that are intelligent, self-sufficient, and curious in terms of form and structure. Energy use in buildings and the production of building materials is an important part of the total energy consumption in today's societies. Humans are currently facing two main problems related to energy consumption: the depletion of energy resources and raw materials and the increase of various types of greenhouse gas pollution (Chayaamor-Heil, & Hannachi-Belkadi, 2017).

With the ultimate goal of discovering those hidden solutions that nature preserves, the interest in biomimicry research has increased, mainly in the field of architecture and engineering, because it offers new and inspiring solutions while creating the possibility of sustainability in the built environment. Some of these solutions are currently in use, although they are not visually appreciated or are blurred due to aesthetics or functionality. Some other solutions are notorious and can be found in big cities or remote areas. In contrast, other solutions may exist only in the mind of an engineer or architect, waiting to be implemented in addition to many other solutions still waiting to be discovered (El-Zeiny, 2012). The researchers presented two main approaches to the biomimetic design process: the problem-based approach and the solution-based approach. The former is driven by inspiration from biology through a non-linear or dynamic progression, which provides feedback and refinement in episodes.

On the other hand, designers look for solutions by defining the problem. This leads biologists to associate the problem with an organism that has solved a similar problem. The second approach is the solution-based approach, which is used when the design process is initially based on the scientific knowledge of biologists and scientists rather than on human design problems (El-Zeiny, 2012) (Martín-Gómez et al., 2019). Besides, transforming strategies available in nature into technical solutions for biomimetic designs can become a complex multidisciplinary process. The complexity of the process increases when conflicts arise by integrating a series of strategies from different organisms to reach improved solutions (Badarnah & Kadri, 2015).

In architecture, biomimicry can be applied to improve the way the built environment is designed through on-site work, construction, and day-to-day operations and to reduce its impact on the natural environment through various strategies to reduce carbon emissions, waste, and more. There is vast knowledge and ideas available to inform possible solutions to architectural design that will also allow designs to be more sustainable. In addition, there are many people involved in the mimicry field who have provided insight on this topic, and the number is growing as it becomes more and more popular among designers looking for a more sustainable future. In architectural design, there are many examples of biomimicry to be found. However, many of these examples use it in different ways. It is often seen not as an overall design solution but instead as a solution to a specific aspect of design (Button, 2016).

There are purposeful ways to use nature for inspiration. For example, the Palazzetto Dello Sport structure, designed by Pier-Luigi Nervi, uses a roof structure that resembles a giant Amazon lily using ribbing to support itself, allowing for a thinner, lighter roof. Likewise, there are uses for mimicry in structures that already use nature. An example is the use of air to create structures, like those in the Douglas River Bridge by Exploration, which uses hollow structures filled with compressed air to create Solid structures (Pawlyn, 2011). These are just a few of the existing examples that represent biomimicry, and there are many more; Nevertheless, as mentioned, many of these designs do not use biomimicry as an overall design solution but rather as a component of a larger element or design (Button, 2016).

The reproduction of natural forms on building facades was the first application of biomimicry in architecture thousands of years ago. Two thousand one hundred years ago, the Roman architect Vitruvius opened a new dimension in biomimicry by comparing proposals for temples to the dimensions of the human body (Elgawaby, 2010). Eight centuries ago in China, the first electronic architects were considered by the rural people of Hongcun Village. They designed their village, giving it the shape of a croak while creating a water web of the water network in the shape of its digestive system (Guillot and Meyer, 2008). Copying shapes, forms, and proposals continued until the end of the eighteenth century as the only application of biomimicry in architecture. The Industrial Revolution added a new dimension to the field of copying existing building systems in plants and animals, and this approach opened the way for a large number of new building designs. The Lily House in Strasbourg and the Crystal Palace in London, designed by Joseph Paxton, are examples of such inspiring constructions (Guillot and Meyer, 2008). In the mid-20th century, Robert Le Ricolais, a professor at the University of Pennsylvania, developed new structural models by copying models of biological structure drawn up by a German biologist named Haeckel during the nineteenth century (Guillot and Meyer, 2008).

In an era of modern and advanced technologies, Nanotechnology, artificial intelligence, information, and telecommunications, it's time to add new values to biomimicry. The new added value was imitating natural systems and processes, looking beyond form and structure, and discovering how natural organisms function to create new building systems (Elgawaby, 2010). Biomimicry is well positioned to play a central role in efforts to solve problems related to health, energy efficiency, and food security. To realize these promises, researchers working in these fields must benefit more from the knowledge and experience of biologists, whether they are ecologists, microbiologists, evolutionists, organisms, cells, or molecules.

Biomimicry is now one of the ways engineers, product designers, and architects do their work. The main reason is that people are looking for more sustainable ways of doing things - to drain energy rather than consume it, to save materials, and to do things in less toxic ways. Living things know how to do these things. After 3.8 billion years, life has learned what is inappropriate and what is appropriate on this planet. In principle, biomimetics can be applied in many fields. Because of the diversity and complexity of biological systems, the number of features that can be imitated is large. Biomimetic applications are in various stages of development, from technologies that may become commercially viable to prototyping (Bharat, 2009).

Organisms have adapted to a constantly changing environment during evolution through mutation, recombination, and selection. The basic idea of the philosophy of biomimetics is that the inhabitants of nature, including animals, plants, and microbes, have the most experience in solving problems and have already found the most suitable ways to survive on the planet. Similarly, biomimetic architecture searches for solutions to build sustainability found in nature (Aziz & Sharif, 2016).

The twenty-first century has seen the ubiquitous waste of energy due to inefficient building designs, as well as the excessive use of energy during the operational phase of their life cycle. In parallel, recent advances in fabrication techniques, computational imaging, and simulation tools have opened new possibilities for mimicry of nature across various architectural scales. As a result, there has been rapid growth in developing innovative design approaches and solutions to address energy problems (Radwan, 2016). Using nature as a benchmark refers to using an environmental standard to measure the sustainability and efficiency of man-made innovations. In contrast, *mentor* refers to learning from natural principles and using biology as an inspirational resource (Aziz & Sharif, 2016).

On the other hand, bio-architecture, also referred to as bio-ornament (Jan, 2016) refers to the use of formal and geometric elements found in nature as a source of inspiration for aesthetic characteristics in designed architecture and may not necessarily be non-physical or economic functions, one example goes back Historicism of bio-architecture to Egyptian, Greek and Roman cultures using tree and plant shapes in the decoration of structural columns(Aziz & Sharif, 2016). The boundaries between the two approaches are blurred with the possibility of transition between them, depending on each case. Biomimetic engineering is usually carried out in multidisciplinary teams in which biologists and other natural scientists collaborate with engineers, materials scientists, architects, designers, mathematicians, and computer scientists (Radwan, 2016).

The field of biomimicry is presently being promoted by two joint organizations, the Syndicate of Biomimicry and the Institute of Biomimicry. “The Guild is the only innovation company in the world that uses deep knowledge of biological adaptations to help designers, engineers, architects, and business leaders sustainably solve design and engineering challenges” (Biomimicry, Entry Portal webpage). “The Institute encourages learning and then simulating natural forms, processes, and ecosystems to create more sustainable and healthful human technologies and designs” (Biomimicry 2008, Entry Portal webpage) (Button, 2016). The institute provides many global design templates, tools, and wiki-based resources to help different disciplines address design challenges. For biomimetics to be useful for the built industry, a design process model must be proposed that “fits” the existing process. The American Association of Architects (AIA) may consider incorporating mimicry into the design process as an “additional service” (2009) consistent with the expertise provided by the architect through program development. It is recommended that all consultants, counting biomimicry, be comprised in the early stages of a design proposal to suggest where mimicry of nature could be most useful (Albertson, 2010).

2.12. Emerging Developments in the Biomimetic Domain

Biomimicry encourages humility, not undermines self-confidence: Biomimicry encourages humility in the face of our natural limits. Humans are not ranked above other species concerning dependence on the environment. We cannot excuse ourselves from our dependence on nature. However, humility is not self-deprecation. The humble person is honest about who he is and does not act as if he were more (Cloud 2007); He's not arrogant, but that doesn't mean he can't be self-confident. Humans could step down from the pillar presented by the Great Chain of Existence and still stand tall. In fact, humility can be a source of confidence. In bio-tradition, humility is seen as "a source of strength, a mechanism of focus" (Benyus 2002). If we admit that all problems cannot be solved by our genius, we are empowered to seek alternative solutions (Orr 1995).

Architect William McDonough is an example of a humble but confident practitioner of biomimicry. McDonough accepted that humanity's continued prosperity depends on the health of the biosphere (McDonough 2005; Braungart and McDonough 2008). McDonough rejects the traditional "cradle-to-grave" manufacturing model, in which 90 percent of materials used in production would be discarded as industrial waste. Instead, McDonough endorses the "cradle to cradle" model. Cradle-to-cradle fabrication simulates the use of a closed-loop material

(McDonough 2005). In nature, an organism's waste is circulated through the ecosystem and becomes a nutrient for other organisms. In "cradle-to-cradle" manufacturing, waste from one production line becomes a feedstock for the other. Products at the end of their life cycle safely enter the environment and degrade into biological nutrients. They are broken down into 'technological nutrients' and recycled – meaning they are recycled to form a high-quality product (Braungart and McDonough 2008). McDonough has designed "cradle to cradle" cities for the Chinese government that can house over a hundred million people. Its hydrological, biometric, wind, and solar energy schemes are respected for each site. In every city, all wastewater is recycled, wastewater is converted to natural gas via constructive wetlands, and solid waste is used as agricultural fertilizer (McDonough 2005).

Biomimicry discourages diminished self-confidence. Indeed, mimicry of nature places great faith in the creative ability of the designer, allowing the designer to apply biological insights in a way that is suitable for human applications. The measure of a good idea cannot be found in nature alone but only in how man adapts it to his ends. Mercedes-Benz engineers turned to nature for advice to design a car with a spacious interior, high stability, high maneuverability, and low drag. When the boxfish (Ostracion Meleagris) emerged as a potential natural archetype, engineers were not deterred by its massive and unintuitive appearance; Staying open, they were able to translate the shape of a boxfish into an aerodynamic concept car, with 20 percent lower fuel consumption compared to similar models (Bartol et al., 2008)

Biomimicry is unconstrained by evolutionary gradation: Nature's designs are developed through natural selection, which continues gradually. The evolved anatomy of an organism is restricted by the anatomy and genetic makeup of its evolutionary ancestors. While nature cannot choose to scan the slab and redesign an organism from scratch, a human designer can overturn existing design concepts and choose to start over (Kaplinsky 2006). The neck of a giraffe can be considered an example of a suboptimal result of the increased design of nature. “No [human] designer can make the neural connection between a giraffe’s brain and larynx by wrapping it down the neck and back into the throat” (Kaplinsky 2006). Nature had limited options due to the anatomy of the giraffe's ancestor, in which the nerve wraps around a blood vessel at the base of the neck (Kaplinsky 2006). Nature is not a designer, so the comparison between nature and designer is a priori wrong. We may talk about "designing" a biological system, but in doing so, we use figurative language. Design requires reflexive awareness, and this ability, as far as we know, is limited to humans and great apes. As such, there is no design in nature in general, only selective processes that respond to direct environmental cues (Capra and Luisi 2014). Rather than comparing human design processes to natural selection, one should consider whether the results of natural selection - thriving biological models - have anything to offer. Biological comparisons can stimulate human creativity in new ways and enhance our ability to solve problems (Wilson et al., 2010).

Moreover, it is wrong to regard the design of the giraffe's neck as an evolutionary mistake. Due to the elongation of the giraffe's neck, it has developed a unique mechanism to prevent fatal hypertension in the head when bent down to drink. The arteries in his neck automatically constrict to prevent blood from pooling by the force of gravity. This mechanism inspired the biomimetic "G-raffe" fighter accelerator suit. The suit's fabric tenses with air pressure, compressing the body in strategic areas to maintain circulation. Wearing this bio-simulation suit, the jet pilot can withstand up to nine G-forces without losing sensory control. Without the suit, the average human would lose consciousness at 4-5 G (Booth 2012). The giraffe's anatomy may be strange, but careful study has shown its ability to inform human design (Gruber, 2008).

Biomimicry of human nature encourages humans to continue building but to make construction consistent with life on Earth in the long term (Matthews 2011). Currently, human production and post-production maintenance often harm the environment. For example, the construction of a large dam requires concrete.

Concrete production results in excessive carbon dioxide emissions. Post-production effects of a concrete dam can include soil erosion, endangering species if bypass dams are not established for migratory species, Disease spread due to reduced water flow and turning the river into a breeding ground for parasites, etc. Nature holds lessons in life-friendly manufacturing and maintenance. Consider the fact that the total biomass of ants on Earth is greater than the total biomass of humans, yet ants do not pollute or degrade their environment (Braungart and McDonough, W. 2008). A tool called Principles of Life, developed by Biomimicry 3.8, summarizes six major principles and 20 sub-principles embodied by most living organisms and ecosystems on Earth. If we use life principles as a criterion for good design, we may achieve the same neutrality that ants have. Our social and economic processes will not create friction with the ecological processes on which we depend (Matthews, 2011).

Biomimetics is a design ethic that emerged from this shift in understanding. The biomimetic design simulates biological systems refined over 3.8 billion years of evolution (Benyus, 2002).

Humans are central to simulating nature, as the approach relies on the designer's ability to extract what he learns about biology into a set of abstract design principles that can be implemented to solve a human design problem. Critics also argue that we should not seek Nature's advice regarding design because Nature designs incrementally. Species are built from a binding mold given by their evolutionary ancestors. This fact does not mean that the results of natural selection have nothing to offer and can infer from a leaf how to harness energy without creating toxic byproducts from the diatom and effectively absorb mechanical stress. Critics also assert that the mission of biomimicry of sustainability forces humans to suppress their drive to build. This relationship between cause and effect is unfounded. Mimicry recognizes that humans and human evolution are in no way separated from the ecosystems in which they exist. Humans are part of nature. As living citizens, our manual labor is as much an expression of nature as it is “the work of a spider or a bee” (Mathews, 2011).

Building must continue, but designs must support life on Earth rather than stifle it. Some critics assert that biomimetic architecture referring to animal and plant forms reflects the impoverishment of human meaning (Kaplinsky 2006). This ignores the evidence that humans have a positive emotional response when their built environment contains naturally occurring geometric shapes of any kind, including plants and animals (Wilson 1984). Architects who embrace mimicry as an approach to sustainable building will incite small shifts in thinking with their biomimetic designs, which in turn may lead to amazing positive changes in the broader world of materials (Meadows 2009) and, thus, human culture. In the words of Pedersen Zare, “Incorporating a comprehensive understanding of biology and ecology into the architectural design will be critical to creating a built environment that contributes to the health of human societies while also increasing positively with the natural carbon cycles” (Zari 2010).

2.13. Biomimicry in Architecture for Extremely Hot Environments

Buildings worldwide use 20-40% of the total energy consumed, largely through the internal heating and cooling of buildings. HVAC systems account for 48-57% of total energy consumption depending on geography (US Energy Information Administration (EIA) 2013), and when lighting is also considered, this figure rises above 65% (CBECS 2012). Higher temperatures in urban climates and an increase in the frequency of extreme heat events are expected to have a significant impact on energy consumption in the future (Huang and Gurney 2016).

The building envelope is the most important structural subsystem influencing the energy balance of a building (Schittich, Lang, and Krippner 2006) and is, therefore, an ideal component for improving thermal behavior. The building envelope is usually a static barrier between external environmental variables and dynamic internal activities. The new architectural trend is to make an adaptive envelope that responds to the changing exterior and interior environments (Armstrong 2012).

The intensity and frequency of heat waves have undoubtedly risen globally since the turn of the century, according to the IPCC's sixth assessment report. By the end of the century, Kuwait will likely become uninhabitable due to a greater percentage of heat-related deaths, according to a temperature and mortality predictions investigation. A 10% to 17% rise in mortality due to heat is anticipated for southern Europe, southern Asia, and China, in addition to central and south America (Alahmad, 2022).

Organisms can adapt to changing weather conditions while maintaining their body temperature in very narrow ranges as they apply physiological, morphological, and/or behavioral means of thermoregulation (Badarnah 2015). In this context, biomimetics (i.e., simulating biological strategies) has enormous potential as a design tool for improving the sustainable performance of buildings. In 1997, Janine Benyus popularized biomimicry as an emerging discipline that mimics nature's forms, functions, processes, and systems to create a healthier and more sustainable planet (Fecheyr-Lippens, 2017).

The use of biomimetics as a design approach to redesigning building envelopes has recently become more widespread (Badarnah Kadri 2012; Gostonyi 2013; Mazzoleni 2013; López et al. 2017). For example, studying how plant stomata function concerning gas exchange has led to the construction of envelopes adapted to changing environmental conditions (López et al. 2015). The banana slug inspired the design of an adaptive enclosure greenhouse that adapts and changes according to weather conditions, collecting rainwater to irrigate plants while storing the surplus for further irrigation (Mazzoleni 2013). However, copying nature does not necessarily lead to more sustainable solutions. It is therefore important to consider different levels of mimicry: form, process, and ecosystem (Benyus 1997). Imitation of natural strategies in buildings can occur on several levels. For example, you could simply create a building that mimics only the aesthetic form (for example, the famous Tirau dog building in New Zealand) or a building that mimics the natural form to provide additional functionality (for example, the glass panels of Waterloo International Station mimic the flexible scale arrangement of pangolins, which allows The building responds to changes in air pressure as trains enter and leave the station) (Zari 2010).

In addition to simulating the shape, it is important to consider the manufacturing process - nature often uses self-assembly and readily available materials (Benyus 1997). To increase the likelihood of sustainable outcomes, the level of the ecosystem must also be considered by considering how the building functions in each habitat and integrates with the urban system already in place (Weissburg 2016; Zari 2017). Using biomimetics to create more sustainable designs requires deliberate practice and a multidisciplinary approach from the outset (Kennedy et al., 2015).

The development of methodological tools to support biomimetic approaches to energy-efficient building design provides a framework for successfully implementing biomimicry (Badarnah and Kadri 2014). Badarnah and Kadri (2014) provide a systematic review of different biomimetic methodologies. Currently, two different approaches have been recognized: either starting from the design challenge, i.e., top-down (Speck and Speck 2008), challenge to biology (Baumeister 2014), biomimetic by analogy, problem-based or starting from inspiring biological observation, i.e., bottom-up, biology-to design (Baumeister 2014), biomimetic by induction, based to Solutions (Vattam, Helms, & Goel 2009)

2.14. Conclusion

Nature has evolved for billions of years. It has developed highly effective systems that are suitable for the intended tasks. Mimicry of nature has been practiced for a long time which has led to the creation of many inventions in all fields. Recently, this approach has been formulated and scientifically regulated under the term 'biomimicry'. Architecture is one such field that attempts to copy nature to enhance and improve its capabilities. It begins by imitating shapes, issues, and structures. It was not until the end of the 20th century that we could imitate natural processes and ecosystems in our buildings. This approach helps humans discover new technologies and concepts to enhance their building systems. One impressive biological process is the climatic adaptability found in natural organisms. Plants and animals provide many examples of adapting to a hot climate through physical properties, behavioral interactions, or cooling processes. Besides these concepts, the normal skin plays an important role, as a thermo-adaptive layer, in regulating the body temperature of living organisms. When this concept is applied to the facades of buildings in hot climates, it means that the facades must be able to deal with the climate, especially natural ventilation, to act as an adaptive layer capable of cooling the interior spaces.

This approach introduces the concept of "breathing walls" for buildings in hot climates, converting them into adaptive walls capable of controlling airflow movement across their entire surface. The conceptual biomimetic model of the “breathing wall” was developed as a new method for controlling natural ventilation through building skins. Applying this concept will turn them into controlled windbreaks. Also, with this approach, the idea of the envelope will be changed to the skin; in other words, the walls will be able to breathe, and the buildings will soon be almost alive.

The built environment represents most global environmental and social problems, with huge proportions of waste, materials, energy use, and greenhouse gas emissions. There is a rapidly growing demand for an effective, sustainable environmental design approach without compromising the needs of society. Although there are currently many approaches to sustainable design in architecture, very few have proven effective on a large scale. Mimicry offers a solution to our sustainability issues. It requires the integration of multiple disciplines working together to produce buildings and systems that are not only more beneficial to their users but also return to nature. Once well executed, imitation can be useful in architecture and the planet’s well-being.

CHAPTER III: METHODOLOGY

The methodology for this dissertation is divided into three parts. First is a qualitative collection of the pledged targets that are promised by the GCC countries, which then is compared to the actions these countries are taking to reach the targets promised by listing recent projects that comply with their responsibility towards the planet. This phase will help evaluate the seriousness the GCC countries are considering when planning for the future of the built environment, especially as a region gaining popularity due to the visible effects of extreme heat in recent years.

Second part summarizes the most appropriate design strategies recommended for this specific GCC climate and evaluates the commitment of the 6 countries in applying them to achieve indoor thermal comfort and to reduce the negative effects of the built environment on the planet.

Finally, a qualitative, interpretative case-study method that samples a total of 9 examples that features of indigenous, vernacular architecture and biomimetic design and cross-references those features with physical adaptations of extremophile non-human species to identify prospects for an architecture that protects humans from increasing temperatures while reducing architecture's contributions to global climate change. For the purposes of this study, the case studies comprise vernacular windcatchers in UAE and Iran, Eastgate Center in Zimbabwe, Matmata village in Tunisia, earth-sheltered homes, the mashrabiyya, and Al-Bahar towers in Abu Dhabi. The extremophile non-human species selected include termites, succulents, and desert animals. The qualitative and interpretive methods will address the gaps in existing bodies of scholarship on vernacular architecture, biomimetic design, and indigenous knowledge, which are considered discrete fields of investigation. The qualitative case studies-based method is selected in this research as it is the most appropriate approach to answer the "how" question and to make an extensive investigation of the existing body of knowledge to draw new conclusions. Specially to compare and contrast historic and contemporary examples such as vernacular and biomimetic projects.

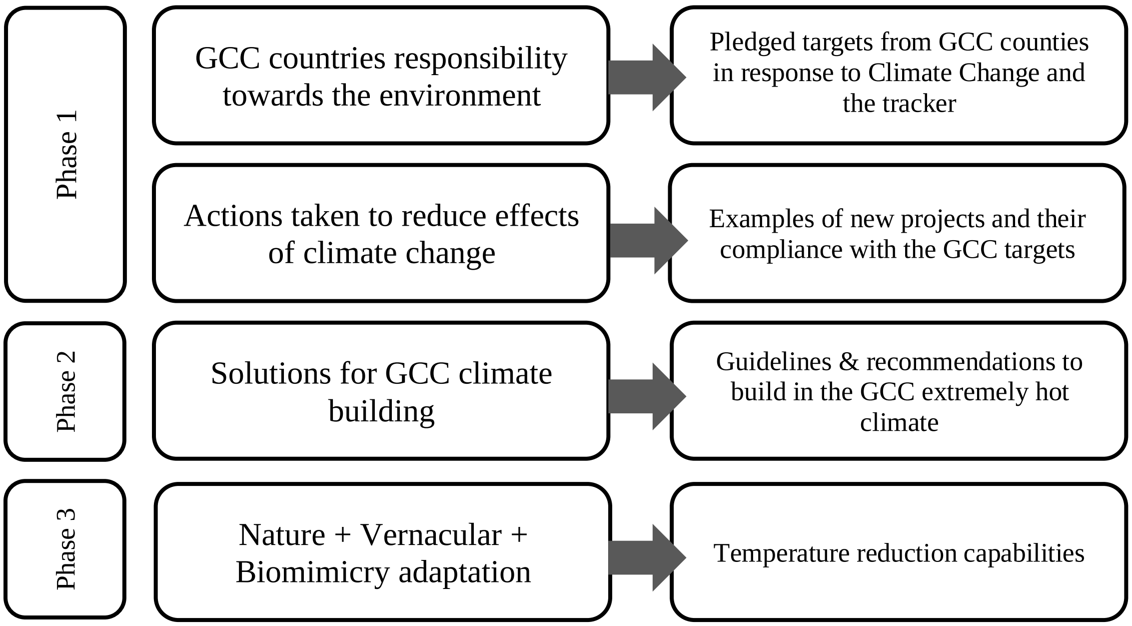

Figure 1 Methodology sequence.

In phase 1, there will be a collection of the GCC countries' pledges as a contribution to the Paris Agreement to participate in reducing the effects of climate change. Then an analysis and summarization of the most recent, innovative projects from the GCC countries that claim sustainable and environmentally friendly designs. The analysis includes an evaluation of the successes and failures of the strategies used to achieve thermal comfort in this hot region and their inclusion of traditional or biomimetic concepts in their designs.

Phase 2 is a collection of the recommended strategies to build in the GCC hot climate. Creating another criteria of evaluating whether these countries are following these guidelines or not to end up with a complete reference to build in the region for future projects.

Phase 3 is the case study analysis that will cover three adaptation strategies as they response to heat in different locations in the world. The analysis criteria will be to; First, understand how each mechanism/element functions within the building. Second, find out how much the selected strategy regulates or decreases the indoor temperature compared to the outdoor temperature. Third, conclude whether the strategy will be sufficient on its own to protect the inhabitants without contributing to the conditions that lead to increased temperatures.

In accordance with the study by PennState University that discovered human tolerance for high temperature is now 31°C when it used to be 35°C in the past (Bohn, 2022), and following the IPCC's announcement of the probability of extremities becoming more extreme and more frequent. This research assumes that we will keep producing the greatest levels of CO_2, and the yearly temperature increase will nearly approach 5 degrees Celsius by 2100. So, temperatures will be the main indicator of success for each case study (when applicable). The temperature readings collected from different existing research will be compared, with 31°C being the current maximum temperature humans can endure indoors before their life is threatened. Each example will be evaluated to either pass or not pass the criteria for creating buildings that protect humans from dying from heat without contributing to the causes of climate change.

The selected case studies will examine three adaptation strategies to respond to hot climates. The strategies (groups) are:

1. Passive cooling.
2. Escaping heat.
3. Reducing surface exposure.

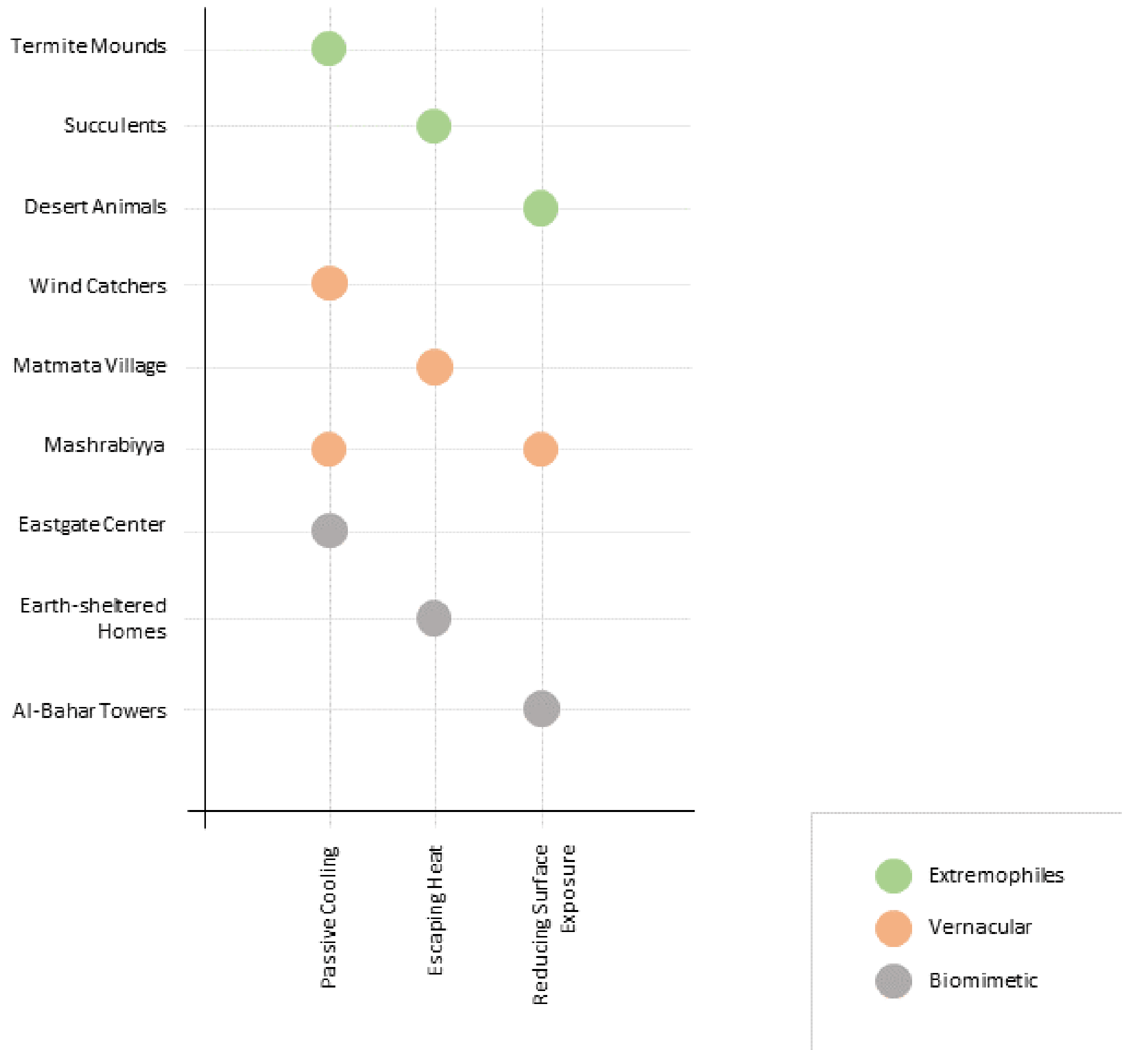

Figure 2 The graph explains where each strategy applies in the case study groups

Each strategy group will analyze three examples:

1. The first example identifies species (including plants) inhabiting extremely hot regions to determine which possesses physical and behavioral characteristics most easily translated into biomimetic architectural design.
2. The second example identifies human societies that have inhabited extremely hot regions for centuries to determine which individual and collective behaviors, material culture

practices, and vernacular architectural forms, features, and materials would readily translate into 21^{st}-century architectural design.

3. The third example identifies biomimetic and vernacular-inspired architecture projects for case study analysis.

CHAPTER IV: DISCUSSION AND RESULTS

4.1.Discussion

The challenging demand for areas in the middle east is that they still want to build high-rise buildings that are dependent on artificial cooling and heating. Modern cities like Kuwait City, which have just recently evolved, are mostly made up of enormous buildings with lightweight construction and a significant percentage of glass that are inhabitable only with air conditioning. According to studies, such a building would experience indoor summertime temperatures of above 50 °C in less than half an hour (Roaf, 2005).

According to the climate fact sheet on a regional level by the Climate Center, Typically, the GCC region has a hot and dry climate, with an arid and semi-arid environment characterizing most territories. The middle east is considered ‘global ground zero’ for climate change and a ‘climate change hotspot’ due to its climate vulnerability. The projected climate indicates that temperatures across this region will increase by 3°C by 2050.

Recent studies have shown that, contrary to earlier theories, people are less tolerant to high temperatures and humidity. It has long been believed that before losing the capacity to control their body temperature, which might eventually result in heat stroke or death, a human could only sustain temperatures of 35°C wet-bulb, comparable to 95°F at 100% humidity or 115°F at 50% humidity. The actual maximum wet-bulb temperature is lower, about 31°C wet-bulb or 87°F with 100% humidity, even for young, healthy people. Given their increased sensitivity to heat, older folks will likely experience substantially lower temperatures (Bohn, 2022).

The intensity and frequency of heat waves have undoubtedly risen globally since the turn of the century, according to the IPCC's sixth assessment report. By the end of the century, Kuwait will likely become uninhabitable due to a greater percentage of heat-related deaths, according to a temperature and mortality predictions investigation. A 10% to 17% rise in mortality due to heat is anticipated for southern Europe, southern Asia, and China, in addition to central and south America (Alahmad, 2022). Unexpectedly, during June to August 2022, 56,303 deaths were reported in England and Wales during heatwaves, despite these nations not having a desert climate. Qatar is facing backlash due to the reported heat-related deaths. More than two-thirds of Qatar's population, which is 2 million people, are foreigners; they primarily come from Bangladesh, India, and Nepal. Over the previous ten years, many of those workers have died, primarily as a result of hazardous working circumstances made worse by extreme heat in preparation of hosting the world cup (Baker, 2022).

According to a conference report by Middle East Institute and Iraq Policy Group in June 2022, discussing the regional policy goals on net zero at 2050. Reaching net zero by 2050 is difficult due to the challenges of meeting those commitments. Of these challenges is that the middle east countries that have low income and cannot make infrastructure-level-changes or their inability to cope with current climate change challenges.

A rising number of nations have committed to net zero emissions objectives after the signing of the Paris Agreement and the publication of the IPCC Special Report on Global Warming of 1.5°C. 33 nations and the European Union have established this goal since March 2022, either through legislation or a policy statement. A net zero aim has been proposed or is being considered by more than 100 nations (ECIU, 2021)

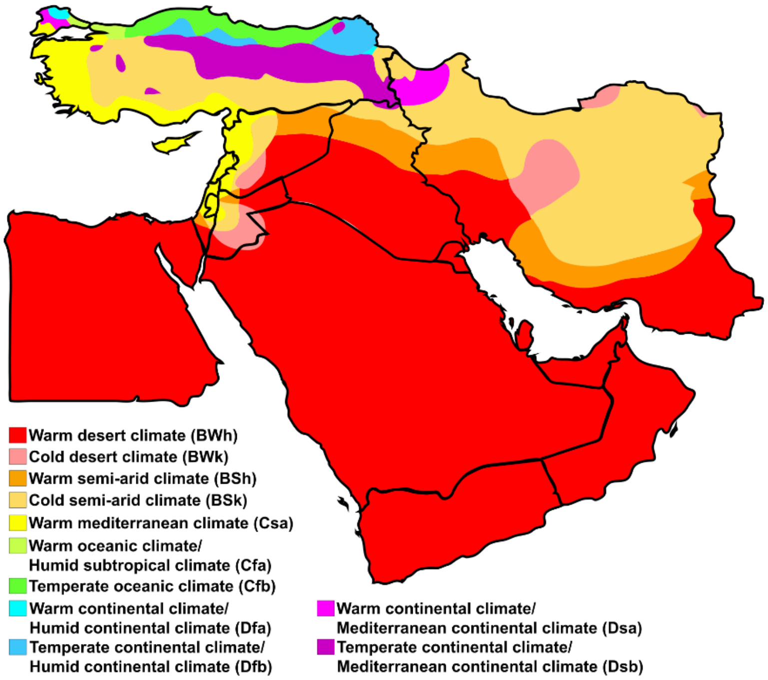

Figure 3 Middle east map of Koppen climate classification

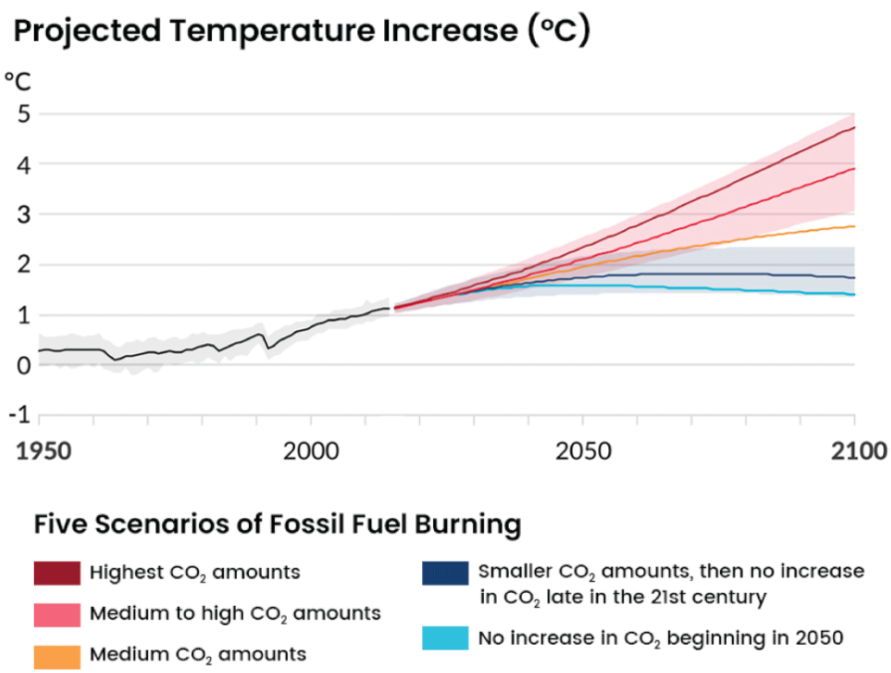

Figure 4 This research assumes that we will keep producing the greatest levels of CO2, and the yearly temperature increase will nearly approach 5 degrees Celsius by 2100.

4.1.1. Phase 1: GCC countries' responsibility towards the environment

Targets Pledges by GCC Countries in Response to Paris Agreement		
Country	Targets	Climate Action Tracker (CAT)
Bahrain	• Actions instead of targets. which involves economic diversification, carbon capture and storage technologies, and focusing on renewable energy.	-
Kuwait	• Kuwait didn't have specific targets but desires to avoid an increase in GHG emissions and move towards a low carbon economy.	-
Oman	• Will control its expected GHG emissions growth by 2 percent to be 88714 Gg from 2020 to 2030.	-
Qatar	• They share four pillars of work which constitute its 2030 vision. The pillars are Human, Social, Economic, and Environmental.	-
Saudi Arabia	• To annually abate up to 130 $MtCO_2e$ by 2030 through contributions that have co-benefits in diversifying the economy and mitigating GHG emissions.	Highly Insufficient
United Arab Emirates	• Pledged to an increase of clean energy to 24 percent of the total energy mix by 2021.	Highly Insufficient

Table 1 GCC countries' responsibility towards the environment

Note: source of targets https://www.un.org/sustainabledevelopment/climate-change/. Sourcse of CAT: https://climateactiontracker.org/

In an effort by the United Nations to combat climate change, the Climate Action development was created in 2015. Countries would participate by pledging targets as plans to follow and aspire to achieve by 2030. Only the GCC countries are displayed in this table however, the climate action tracker ranking is not available for all the countries yet. This table was re-interpreted from the Climate Center fact sheet of the middle east on a regional level. The information presented here will be used to evaluate the selected project of each country after their pledges in 2015 and whether they are working towards their future targets. Several countries in the Middle East are putting laws into place to support a built environment that is more sustainable.

Over the past 10 years, these initiatives have intensified across the GCC nation as they are considered to be the countries with the most temperature highs recorded recently.

GCC Countries Projects Examples								
Country/City	Highest Temp. (Summer)	Project	Year	Strategy	Materials	Traditional	Biomimetic	Energy Efficient
Bahrain, Manama	47 °C	Bahrain Bay Tower	2015	Panel-like system of sliding aluminum louvers for privacy and shading against extensive glare.	Treated glass	No	No	No
Kuwait	54 °C	National Bank of Kuwait	2011 - 2020	• Energy-efficient passive architecture that shields the offices. • Series of concrete fins are integrated along the sun path and extended across the full height of the tower, providing structural support and shading.	Concrete and glass.	Yes	No	Yes
Oman, Halban	51.6 °C	History of Science Center	2016	• The width of the facade pattern fluctuates in accordance to the sun direction; adding to the visual significance of the structure as well as becoming a light and temperature controlling element of the space. • The entire internal surface is also inclined as an additional temperature control element.	Outer shell: Concrete wall construction: AAC block Glass sections: Thermal brocken aluminum profile with low heat transfer double glazed system. Main staircase: solid wood.	Yes	No	Yes

GCC Countries Projects Examples								
Country/City	Highest Temp. (Summer)	Project	Year	Strategy	Materials	Traditional	Biomimetic	Energy Efficient
Qatar, Doha	50.4 °C	The National Museum of Qatar	2019	• A steel frame that spans an insulated waterproof superstructure supports the interlocking discs, which are clad in a glass-fibre reinforced concrete with a sandy hue that evokes the desert landscape. • Sections of the building's shell protrude outwards to shade areas of a central courtyard, and to protect the interiors from direct sunlight. • The galleries surround a central courtyard that references the traditional Baraha where travellers would unload their merchandise.	Steel Glass-fibre Reinforced concrete	Yes	Yes	No
Saudi Arabia, AlUla	41.5 °C	Banyan Tree AlUla	2022	• The site's natural habitat is preserved. • The use of local resources, craftsmanship, and minerals further minimizes the project's carbon footprint. • The architects used water harvesting techniques to guide the rainwater towards micro-catchment gardens to support plant life on the site. • The canvas acts as a double layer to create natural cooling between the roof and the tent. • All walls are finished with a locally sourced mud coating.	Compacted sand: Façade. Canvas: Tent shading. Mud: Wall coating.	Yes	Yes	Yes

GCC Countries Projects Examples								
Country/City	Highest Temp. (Summer)	Project	Year	Strategy	Materials	Traditional	Biomimetic	Energy Efficient
UAE, Abu Dhabi	52.1 °C	Anwar Gargash Diplomatic Academy	2021	• introverted building was created, with the play of outer opacity and internal transparency serving as a major motif. • The building's envelope designed to combat the harsh elements of the regional climate, while also representing the nation's strength. • Concerns of sustainability are addressed via the double skin façade. A high-performance glazing system is the first defense against solar heat gain, doubled by an outer skin of perforated aluminum screens. These panels diffuse sunlight throughout the interior, without obstructing views.	Façade: Aluminum screens Stairs: Wood.	Yes	No	Yes

Table 2 GCC Countries projects examples

The previous table displays one project for each of the GCC countries, which are commissioned and completed after the pledged targets were submitted. The investigation aims to evaluate the country's commitment to meet their targets in accordance to the Paris agreement. So far, it is noticed that the current projects in the desert-like GCC climate is moving towards modernist architecture projects with high rise buildings. It is very predictable that the efforts put forward for the GCC countries would be for commercial and hospitality more than residential projects.

Traditional and biomimetic design approaches do not seem to be a priority in the design, however, energy efficiency is considered, like the case of The National Bank of Kuwait, which is waiting on its LEED certification even though the selection of materials is not environmental as concrete co2 emissions rise and the extensive use of glass in an increasingly hot environment is not advised as it will push the building to use more energy to cool the interiors during the day if not relying on renewable energy resources.

4.1.2. Phase 2: Recommendations to build in GCC countries climate

In many Middle Eastern countries, the environmental impact of cooling buildings in the summer is significant. The high peak in electricity consumption caused by air conditioning and the low efficiency of the power plant units because of the high inlet air temperature are two issues that arise during the summer (Wahl, 2017).

Rank	Country	Consumption (kWh/year)
1	Saudi Arabia	134,900,000,000
2	Egypt	78,160,000,000
3	United Arab Emirates	38,320,000,000
4	Kuwait	35,520,000,000
5	Iraq	33,300,000,000
6	Syria	25,280,000,000
7	Algeria	24,900,000,000
8	Libya	13,390,000,000
9	Tunisia	10,760,000,000
10	Lebanon	10,670,000,000
11	Oman	9,582,000,000
12	Qatar	9,053,000,000
13	Jordon	7,959,000,000
14	Sudan	2,943,000,000
15	Yemen	2,827,000,000

Table 3 electricity consumption in the Arab Countries (2003).
Source: Proceedings of the Tenth International Conference for Enhanced Building Operations, Kuwait, October 26-28, 2010 (Hanna, 2010)

Recommendation	**Objective**
Courtyard & Windcatchers	Ventilation (passive cooling). Indoor thermal comfort Energy efficiency Privacy.
Thick walls (thermal mass) + Insulation	Indoor thermal comfort. Acoustical privacy.
Local building materials	Cost efficiency Environmental
Small openings/Treated glass	Reducing overheating and glare. Privacy.
Solar energy	Energy efficient.
Shading devices	Reducing overheating and glare. Privacy.

Table 4 Recommendation and objectives

Since mechanical cooling systems are frequently used in Saudi Arabian buildings to maintain thermal comfort, an effective plan for lowering total energy usage is needed. The improvement of thermal resistance in building envelopes (walls and roof), application of advanced window systems (WWR, glazing type, and shading devices), airtightness measured by infiltration rate (i.e., air changes per hour ac/h), and use of efficient AC systems were some of the target areas that needs to be developed for the future of the built environment in similar climate zones.

According to the table ranking arab countries' electricity consumption in 2003, five out of 6 countries of the GCC countries are ranking in the top 15. This significant high number of electricity usage can be reduced if those countries followed the recommended solutions for their climate zones and were able to make use of the abundant renewable energy sources in the region.

4.1.3. Phase 3: Vernacular and biomimetic qualifications to reduce indoor temperature

In the natural world, organisms adapt to their environment in a specific way to survive. An organism's reaction to an external stimulus to preserve its physiological state is called a physiological adaptation (Rehman et al.,2021). A structural or geometrical aspect of an organism's morphology is a morphological adaptation if it aids the organism's adaptation to a given environment and provides improved functioning for survival. The term "morphological adaptation" refers to a structural or geometrical trait that improves an organism's ability to respond to a given environment and permits improved functioning for survival. Examples of morphological adaptation include size, shape, and pattern (Rehman et al.,2021).

Current building designs consider the envelopes to be a thermal barrier. They often aim to prevent any transmission between the internal and external environments by improving the insulation of the exterior, which kills any connection between the inside temperature and the outer environment (Pawlyn, 2011). In contrast to this building technique, organisms can successfully control their temperature by maintaining an acceptable balance between the amount of heat they absorb and the amount of heat they lose. It may be accomplished using flexible behavioral or physiological strategies. Such as the case of the ectotherms and the endotherms animal groups. Ectotherms are a group of creatures that include amphibians and reptiles that rely heavily on their external surroundings to control the temperature of their body. In contrast, endotherms, regardless of their surroundings, retain a consistent body temperature. Architects can take advantage of that concept in creating more buildings that react to their surrounding environment. The example groups included in this study begin with extremophiles, then indigenous cultures strategies that resulted in vernacular architecture, and finally, contemporary biomimetic architecture examples.

The projects selected for the group studies present their ability to maintain the required thermal comfort level for human survival in an indoor environment. The geographic distribution of the species, indigenous traditions, and vernacular traditions below is spread to cover as many areas as this research would allow. However, this helps each of those adaptations individually and, most importantly, in combination, to keep the interior space of the building below the threshold of human tolerance with or without mechanical aspects.

4.1.3.1. **Group 1: Passive Cooling**

The cooling, ventilation, and lighting demands of a home may be met with passive cooling since it relies on clean, renewable energy sources like the sun and wind. When used effectively, passive cooling may lessen the temperature differential between the inside and outside of a structure, enhance the quality of the air within, and make the space more pleasant for its occupants.

The amount of energy used and the effects on the environment, such as emissions of greenhouse gases, may be lowered as a result. Sustainable architecture, including passive design for heating and cooling, has gained popularity in recent years, especially in the past decade. Envelopes with careful planning provide maximum airflow and sun rejection in the warmer months. In a hot, dry region like Iran, various passive cooling methods are appropriate. Design strategies that reduce the need for mechanical cooling systems include strategically placed windows and skylights, appropriate glazing for windows and skylights, appropriately sized shading of glass when heat gains are being avoided, the use of light or reflective-colored materials for the building envelope and roof, as well as careful siting, wise orientation decisions, and appropriate landscaping. (Ran, J., & Tang, M. 2018). This section will discuss the first group, which includes Termite Mounds, Windcatchers, and Mick Pearce's Eastgate Center.

4.1.3.1.1. Termite Mounds

Location: Harare, Zimbabwe.
Climate zone: Temperate highland tropical climate with dry winters.

Termites are tiny insects that live in colonies, which build nests called "mounds" as a defense mechanism against the elements and predators. Because of how well they keep the inner temperature stable. Central shafts, numerous peripheral air passageways, and porous surfaces make up termite mounds. They can grow to be as tall as eight meters. The environment, the species, and the intended purpose all have a role in shaping the appearance and function of these mounds (Faragalla & Asadi, 2022).

Mounds structures can take many shapes in the wild, including flat hillocks, cathedral mounds, and dome-shaped ones. The cathedral-shaped termite mound has been the focus of most research because of its unique ventilation system (Faragalla & Asadi, 2022). Differences in wall porosity, thickness, surface design, and mound interior structure characterize each type of structure. The chimneys on some of them are open, whereas, on others, they are closed. The termite mound's orientation and placement are major elements in the construction process that are directly connected to its environment.

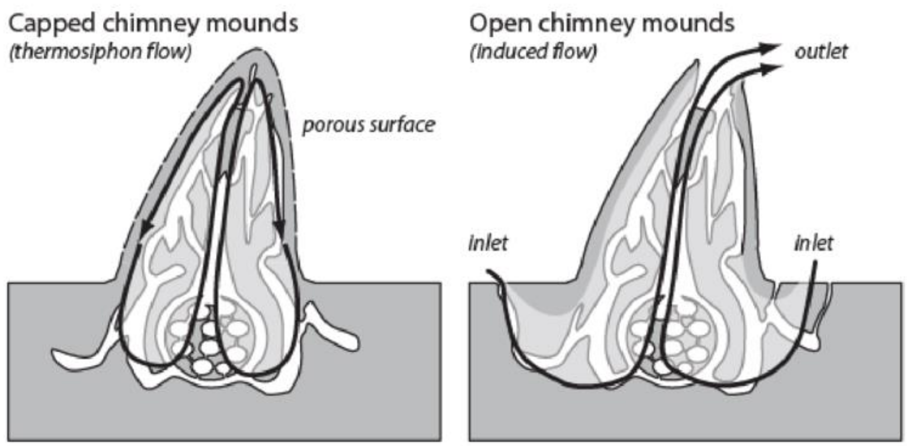

Figure 5 Termite mounds cross-section

The nest temperature of termites is around 30 °C, varying less than 3 °C daily and barely 1 °C annually, and this has been noted for the first time by Gomaa (2012). He postulated the thermosiphon idea to explain the mound's temperature control mechanism. Gomaa (2012) estimates that there are two million termites in a 20-kilogram termite mound, requiring a great deal of air for gas exchange. He hypothesized that the heated air rises via the central shift pushed by buoyant forces in a closed mound with no visible outlets but a porous surface because of the high metabolic rate produced by the colony (about 100 watts). As a result, air from the outside is drawn into the ridges' internal air passages, where breathing gases, heat, and water vapor can be exchanged. The thermosiphon effect draws in cooler, denser air from above and forces it downward, where it cools and refreshes the nest.

Studies show that the open-chimney mound has a more effective ventilation system as it grows vertically, creating a more conducive framework for air circulation. The Upper, huge vent of the mound (chimney) has a better possibility of good ventilation than apertures in lower levels due to greater exposure to wind velocity (Hassan & Sumiyoshi, 2018). Due to the Venturi effect, the air in the nest is sucked out of the mound through the upper chimney exit, while new air is brought in through the lower vents.

Further studies by Imani & Vale (2020) provide evidence for their idea by analyzing data on heat, carbon dioxide levels, and wind patterns around two distinct Macrotermes bellicosus mounds, which are built by the largest termite species found in Africa and south-east Asia. They argued that the cathedral-shaped mound in the savannah was created by a temperature difference caused by the sun heating the air in the channels through the thin walls of the ridges. As a result, there is a better chance of gas exchange with the outside air by diffusion through the ridged wall's relatively thin thickness. The stack effect causes convective flows to climb from air channels at the mound's periphery to the mound's peak, descending the central shaft and into the nest. Because the outside brings on the temperature differential, this process is called "externally driven ventilation" (Imani & Vale, 2020). The temperature gradients caused by the metabolism of fungi and termites drive the internal ventilation in forest mounds, as Lurcher's thermosiphon hypothesis predicted.

4.1.3.1.2. Windcatchers

Location: Yazd, Iran.
Climate zone: hot desert climate.

The windcatcher is a common method in vernacular architecture for bringing fresh air into buildings without requiring artificial ventilation. These windcatchers have been utilized for construction in the Middle East for over three thousand years. The earliest proof of these elements goes back to 4000 BC and was discovered at the Tappeh Chackmaq site near Shahrood, Iran. In various parts of the world, locals refer to them by names like Badger and Malghaf. A windcatcher is a tall structure, often between 3 and 33 meters in height, that is installed on top of a building (Martorell & Patio, 2006). Historically, the windcatcher's design varied in tower height, number of apertures, opening placement, the cross-section of air channels, and tower orientation while paying respect to the building's construction based on the economic and social standing of the house landlord.

Roaf (2005) listed the uses of traditional windcatchers as below:

1. To provide basic ventilation, as in Baghadad.
2. To provide convective cooling for people where they supply indoor temperatures between 25-35 C.
3. To provide evaporative cooling of people at temperatures above 35 C.
4. To cool the structure of buildings down by either coupling the internal air temperatures to those of the night sky or with the earth in basements and underground tunnels and streams, typically in regions too hot for internal convective cooling to be enough during the day.

The windcatcher captures the breeze and directs it down into the rooms. These towers function by leaving just the shaft against the incoming wind open and guiding cold air flowing at higher levels downward through vertical holes with oblique sides (also known as directed openings). Once the cold air has entered, the heated air that has been flowing indoors is forced out via apertures made on the windcatcher's opposite side.

Unidirectional and multidirectional wind catchers are the two primary classifications of wind catchers based on their outward shape. This second category includes the square plan, hexahedral, and octahedral wind catchers, as well as the more common two- and three-sided wind catchers.

Many nations in the Middle East where homes are built in areas with a constant prevailing wind have benefited from using a unidirectional windcatcher. The system's effectiveness is highly sensitive to wind direction. A single-sided windcatcher will not work well if the wind blows in the wrong direction. Therefore, the inlet ports of the windcatcher should be as high as possible to benefit from the stack effect (buoyancy effect), much like a solar chimney would in that particular circumstance (Khelil & Zemmouri, 2018). A one-sided windcatcher consists of a single hole through which the wind enters, travels through the interior, and exits through the various vents, doors, and windows.

Wind catchers with two vents and two separate halves are commonly used in high-wind areas. Providing (suction) and extracting airflow from the bidirectional wind catcher are depicted as two independent channels (Khelil & Zemmouri, 2018). The main benefit of this device over a conventional one-sided windcatcher is the incidence angle since the airflow rate through a conventional windcatcher's unidirectional tower aperture approaches zero as the transition angle approaches zero.The three-sided wind catcher typically has a bigger windward side with more apertures to harness the prevailing wind. The swooping shape of the apertures of a wind catcher boosts the incoming air's velocity. Researchers have found that four-sided windcatchers are more common in the Middle East than their two- and three-sided counterparts. Four-sided windcatchers are common in locations with inconsistent wind patterns because their structure is built to take advantage of airflow from all directions (Xue & Liu, 2011).

A study by Roaf (2005) in Yazd, Iran investigated the difference between the indoor and outdoor temperatures of a traditional home that uses the windcatcher strategy with the cooling water qanat and an electric fan (operated by PVs) to provide the home with passive ventilation and regulate the indoor temperature. The results read an indoor 25 °C temperature at the basement level while the outdoor reads 40 °C. Yazd's climate is a hot desert climate. This traditional strategy achieved an internal temperature of 25°C, which is 15°C less than the outside temperature. Unfortunately, the study does not detail the season of the reading. Still, the assumption in this case is that if the outdoor temperature reached 55°C, then the indoor temperature would be 40°C, which is 9°C more than the human tolerable temperature of 31°C.

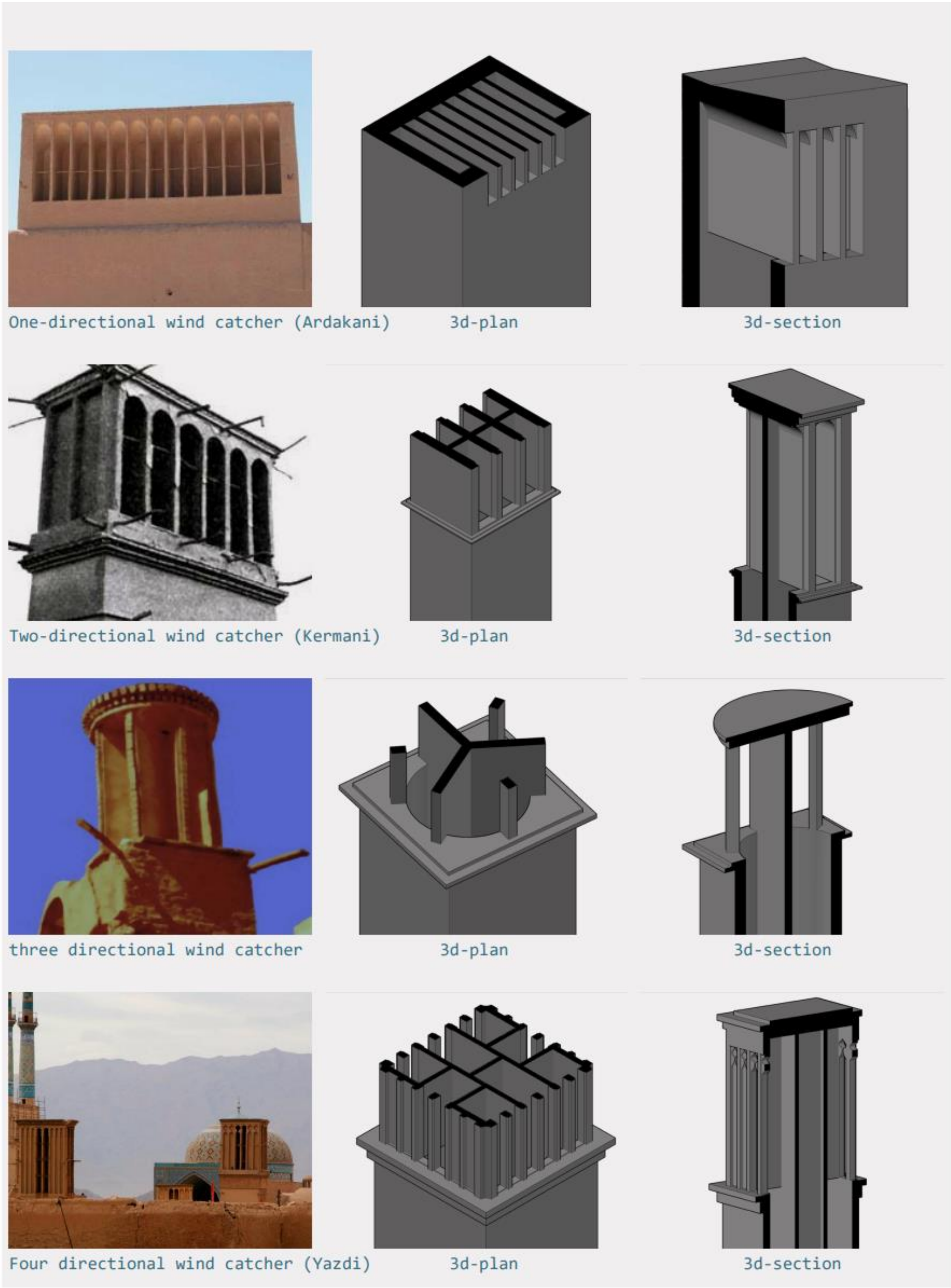

Figure 6 Windcatcher types.

4.1.3.1.3. Mick Pearce's Eastgate Center

Location: Harare, Zimbabwe.

Climate zone: Temperate highland tropical climate with dry winters.

Harare's Eastgate center is an example of architecture that bridges the gap between vernacular building strategies and modern technology using the blend of steel and glass with newly constructed brick and stone materials (Xue & Liu, 2011). A regionalized style that considers the local ecosystem, the historic traditional stone building of Great Zimbabwe, and the available labor force. The center was designed around passive cooling techniques, significantly reducing the energy needed for air conditioning. The design's brilliance lies in how it mimics several types of thermocontrol mounds within a single highly useful structure (Hassan & Sumiyoshi, 2018).

Located in Harare, Pearce's practice focuses on economically and environmentally sustainable construction. Harare International School Arts Centre, Harare Hindoo Temple, and Chinhoyi Provincial Hospital are just a few of the buildings in Zimbabwe that he designed. Each structure here makes the most of its available resources. In 2003, Pearce was recognized for his work in the Eastgate community with the Prince Claus Award for Cultural Development (Khelil & Zemmouri, 2018).

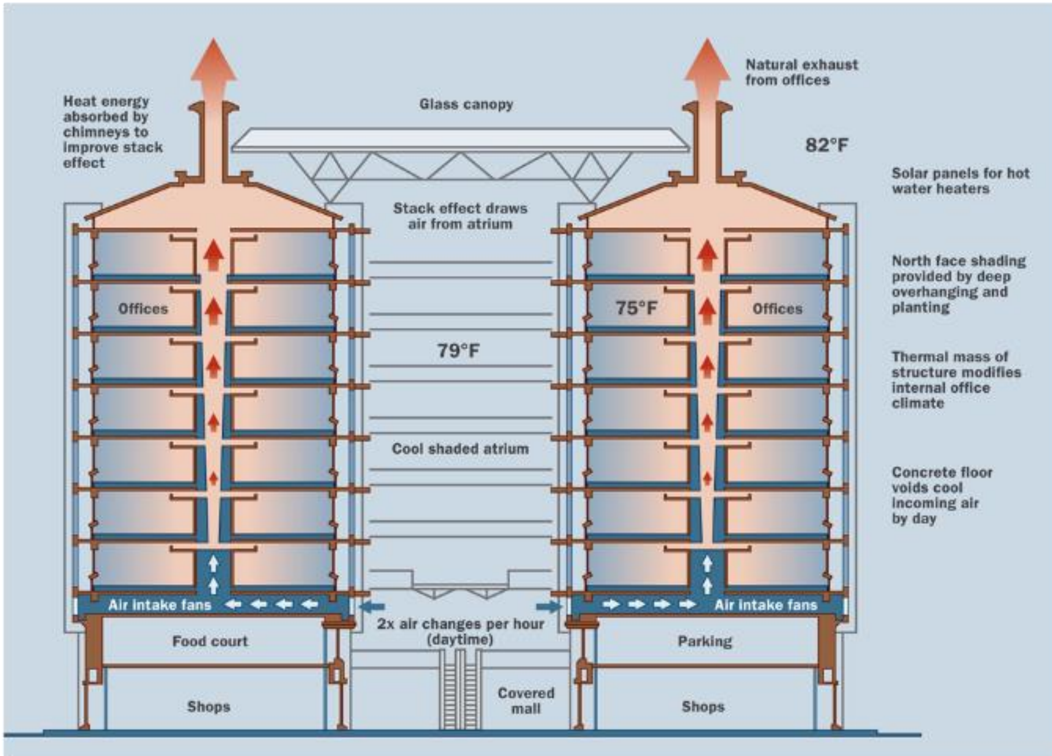

Figure 7 Eastgate center ventilation section.

During the day, the new order's enormous jutting stone features block the sun from shining through the small windows, while at night, the increased outside surface area of the structure allows for more efficient heat loss and less solar gain. The granite aggregate in the precast concrete was scraped away to make them seem like the lichen-covered boulders seen across the rural terrain of Zimbabwe. The steel rings supporting the green vines interrupt the horizontal protruding ledges, reintroducing nature to the urban environment (Ran & Tang, 2018). Pearce used deep overhangs to shield the windows and walls from the sun, and the adjustable blinds helped with this. In Africa, covering the walls with deep eaves is common to protect them from the scorching summer sun while letting the lower winter sun warm the interior first thing in the morning.

Moreover, because local termites have been using passive cooling for thousands of years before humans, such systems are well-suited to this region of Africa. Flues vent through the top and sides of termite mounds, and the mound is constructed to catch the breeze (Martorell & Patio, 2006). Termites help direct air movement by opening and closing tunnels to regulate ventilation as the wind blows through the structure's main chambers below the ground.

The walls of the building have been created using a blend of steel and glass. The blend is an effective way of handling temperatures without the use of other artificial means. During the day, the walls prevent the sun from entering the building by reflecting its rays. This technique ensures that a significant amount of heat is absorbed during the day. When the building is cold at night, the heat absorbed during the day is released and used to warm the interior. Like termite mounds, the Eastgate center uses natural ventilation to handle temperature by ensuring the occupants don't suffer from extreme temperatures day or night.

The sustainable layout benefits the present generation without jeopardizing future generations. Eastgate in Harare unites the city's past and present with its combination of traditional brick and stone with modern steel and glass. It has been replaced by a regionally appropriate fashion that values the conservation of natural resources, respect for the ancient Great Zimbabwean heritage of building with stone, and the employment of locals.

The same year of the project completion, members of Arup's architectural group moved into the building to collect preliminary readings of indoor temperature and energy performance. The indoor temperature on September 26th, 1996 maintained its stability against the outdoor fluctuating hot temperature, which is a reading that was taken before the fans were optimally operated (Smith, 1997).

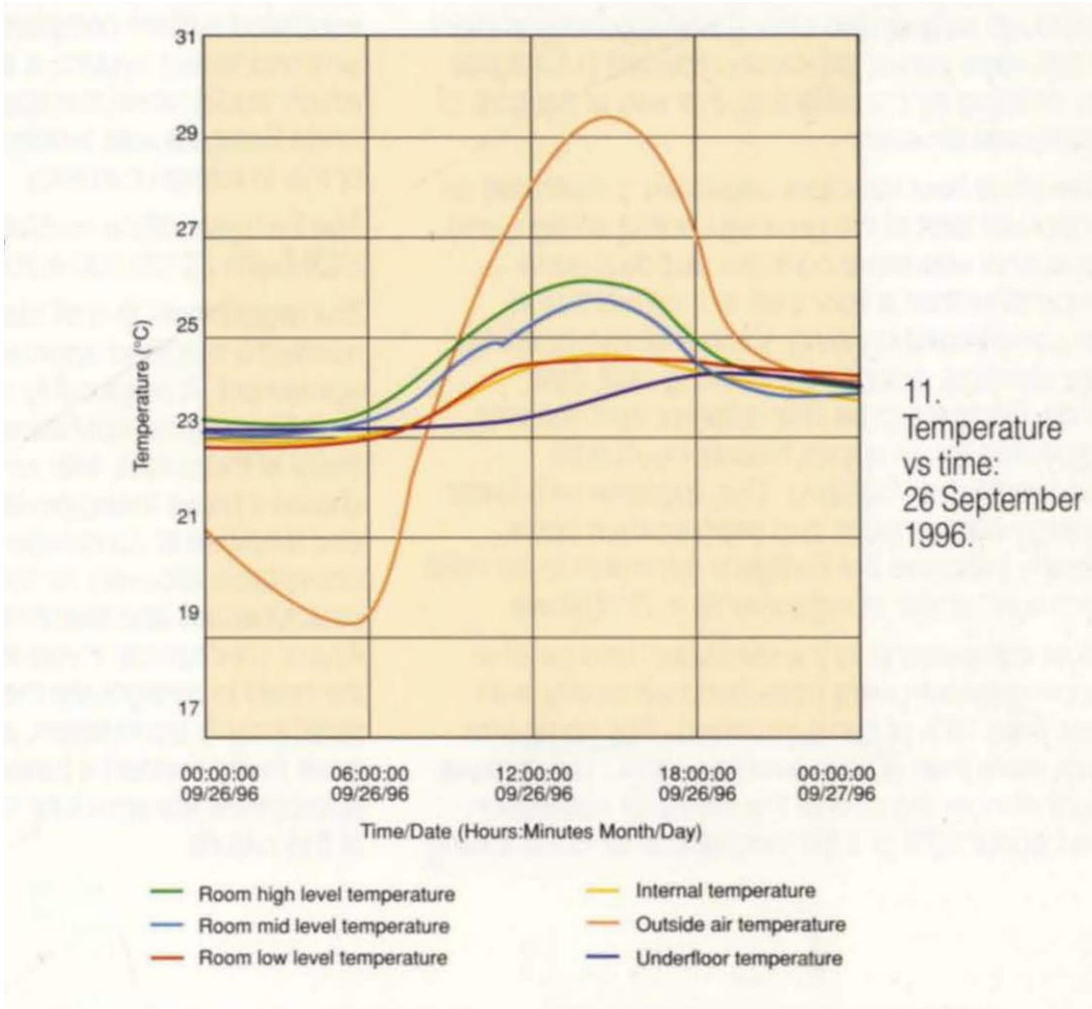

Figure 8 Eastgate Center temperature reading on 26 September 1996

Termites protect themselves from predators and unsustainable weather conditions by building mounds. Indigenous people share a connection to nature with other nearby species that share the same climate characteristics. They evolved a method of creating interior thermal comfort similar to the termites to be protected from the intense heat of their environment. The strategy they used for naturally ventilating a structure is building windcatchers. Inspired by termite mounds and similarly to vernacular chimneys, Mick Pearce's Eastgate Center is an example of how architects can use the ectotherm’s features to create designs that will be effective in extreme heat. Humans can harness these shared solutions to diminish the indoor-outdoor separation imposed by the International Style by allowing humans to have breathable buildings.

4.1.3.2. Group 2: Escaping Heat

Species living in the desert developed ways to escape direct sun's heat. Plants, insects, and humans have coped similarly to protect themselves. The second group analyzes the Ariocarpus fissuratus (desert succulent), vernacular underground villages, and earth-sheltered homes within the same category.

Succulents can survive in some of the hottest places on Earth. The aesthetic and functional needs of Matmata's citizens were met by the city's troglodytes. These cave dwellings showcase remarkable human resourcefulness and tenacity in hardship. Modern earthen shelters sometimes include steel-reinforced concrete for structural support, which reduces the shelter's sustainability but greatly increases its lifetime.

4.1.3.2.1. Ariocarpus Fissuratus

Location: Northern Mexico and Texas, United States.
Climate zone: Arid desert climate.

Succulents, the little desert plants, thrive in some of the hottest conditions on Earth. Due to the high levels of direct sun radiation, soil surface temperatures can rise beyond 70 degrees. Friction and decreased wind speed, which may be further impeded by rough or uneven terrain, further limit the amount of cooling that may occur near the soil's surface. Because their stomata close during the day, crassulacean acid metabolism plants like the so-called living rocks in the Aizoaceae, like Lithops species, and Cactaceae, like Ariocarpus species, have a hard time using transpiration to cool themselves. If a little succulent's stalk is buried deep enough, its temperature can be maintained at more manageable levels. In the case of Lithops species, which have transparent tissue (or "windows") close to the shooting surface, the photosynthetic tissue at the base of the leaves stays relatively cold since it is positioned so deeply below the soil. However, for windowless succulents like cacti, the soil around their photosynthetic tissue can reach much hotter than the air temperature a few millimeters above it or the soil temperature a few centimeters below it, which makes this growth type potentially problematic (Geiger et al., 2003). It is hypothesized that Ariocarpus fissuratus and other living-rock cacti protect themselves from lethal temperatures through root or shoot contraction, which entails burying a large portion of the shoot beneath the soil's surface.

Ariocarpus fissuratus is a type of succulent plant that is found in deserts. These succulents are known for uniquely surviving the extreme temperatures of deserts. During the day, the temperatures in the desert go up to 70°C. Such temperatures will kill the enzymes in a plant and make it die. However, that's not the case for Ariocarpus fissuratus. These succulents close their cuticles during the day, making it even more impossible to regulate their temperatures through transpiration (Primrose, 2020). The strategy Ariocarpus fissuratus uses to escape the desert's heat is having a significant portion of its plant deep into the ground. The roots and shoots are buried deep in the ground to avoid extreme temperatures and loss of water. The plants survive by taking nutrients from the soil, and the soil beneath absorbs the heat. Such mechanisms have enabled most desert plants to survive both herbivores and extreme temperatures. The herbivores don't see the significant portion of the plant and therefore don't eat it.

Figure 9 The living rock cactus

128 *The Temperature of the Surface of Deserts*

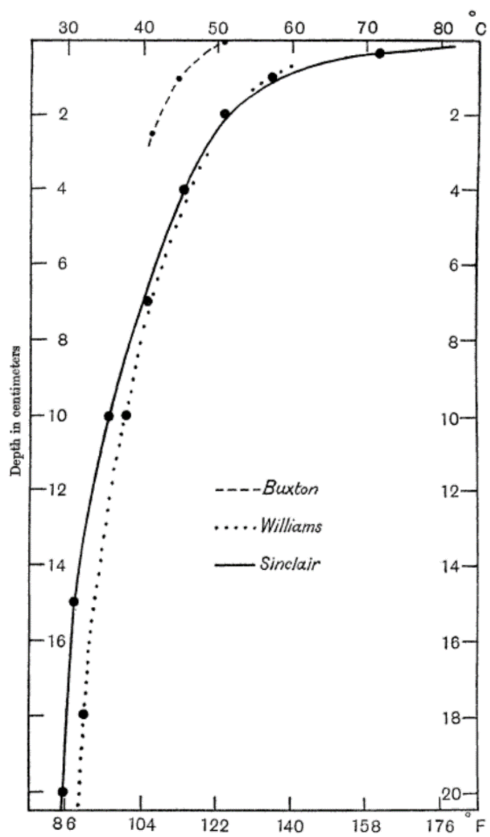

FIG. 1. Graph showing temperatures at various depths in desert soil. A similar graphical method might be developed for obtaining the surface temperature by deduction from that shown by thermometers buried at various depths.

Figure 10 The temperature of the surface of the desert.

Root or shoot contraction may have additional benefits for small succulents. Plants that are very small and grow close to the soil's surface are often called "living rocks" because they may go unnoticed by herbivores. Putting the bulk of the branch below the soil surface, as was done by two species of Lithops, can help reduce water loss due to evaporation. Plants may profit from contractile roots by placing themselves lower in the soil, where moisture is more likely to persist for longer than at the surface, but this would require the formation of new roots at a deeper depth. Many Agavaceae species, including succulents of the desert and species native to dry regions, have roots that are more contractile than their corresponding roots, suggesting that this characteristic is unique to monocots. Plants that grow via cloning could spread their offspring far from the original plant by sending out new roots that can contract. The final benefits of contractile roots include helping plants, especially seedlings and those of short height, to attach in sandy or shifting soils common in desert environments (North et al., 2008)

Several succulent plants have been reported to have contractile roots; these include the Asphodelaceae, the Agavaceae, the Neo Mammillaria MacDougall, and the Pediocactus spp. (Sivin, 2003). However, in the family of Lithops, although several descriptions of A. fissuratus's growth pattern, the species' roots are contractile; no cactus, including A. fissuratus, has offered conclusive anatomical evidence or quantitative assessments of contraction. Small globose succulents may experience confusion between root contraction and shoot contraction because of water loss during drought.

Shoot temperature can be affected not only by internal plant characteristics but also by external variables and factors which affect the surface soil temperature. Features like pebbles that reflect or deflect sunlight can significantly lower daytime soil surface temperatures. A variety of tiny succulent species prefer the cooler temperatures that may be found on rocky surfaces, such as quartz outcroppings. A. fissuratus, like other members of its genus, is commonly found in rocky soil, where it may benefit from, among other things, soil moisture retention, herbivore protection, seed germination microsites, and mineral nutrient retention (Lopez et al., 2009).

4.1.3.2.2. Matmata Underground Village

Location: Matmata, Tunisia.
Climate zone: Hot, arid summers and cold, dry winters.

Matmata's troglodytes found shelter from the heat in their underground homes, which were well suited to their practical requirements. These underground homes are incredible examples of human ingenuity and resilience in the face of adversity. This success resulted from a lengthy process of trial and error passed down through generations. Houses built in the Matmata style are eco-friendly, cost-effective, and energy-efficient (Imani & Vale, 2020). They can easily ensure the economic sustainability of the whole settlement and serve as a great source of inspiration for many disciplines, including architecture, environmental studies, and ecotourism.

The vernacular method of these underground homes can provide acceptable comfort conditions and air quality for inhabitants and reduce energy consumption using passive cooling measures, as described by a typical low-rise residential building in a semi-desert location during hot and dry weather (Hassan & Sumiyoshi, 2018). Due to its special strategy of underground dwellings, the homes in Matmata village will keep an 18 °C indoor temperature while the outdoor temperature would be 50 °C.

The underground building structure is one of the passive energy solutions that exemplifies man's fight to stay alive and find refuge from harsh environments while providing a secure and comfortable home. From the Henan, Shanxi, and Gansu provinces in Northem China to the

Mediterranean regions of Sicily, Santorini, and the Goreme Valley of Cappadocia in central Turkey, these indigenous designs have been used by locals for centuries (Badarnah, 2017). Matmata, in southern Tunisia, is a model community of earth-sheltered dwellings. The very definition of vernacular architecture is found in how its designs are tailored to the requirements of the local population and the way of life.

Figure 11 Matmata city, underground homes.

There are three basic types of underground houses: underground buildings integrated into the existing ambient, true underground buildings, and bermed earth-sheltered buildings. Matmata village dwellings are the first type of these houses. The dwellings are constructed by drilling holes into the ground to serve as courtyards and then cutting dry vertical earthen "walls" to form the interior spaces of the houses. The consistent temperature of this sort of underground dwelling makes it possible for these units to function properly, even during the winter (Milanović., 2018).

4.1.3.2.3. Dobraca Bermed Earth-Sheltered House

Location: Kragujevac, Serbia

Climate zone: Continental with hot summers and cold winters.

Earth shelters of today typically employ substantial amounts of steel-reinforced concrete as structural support, thus diminishing the building's sustainability while dramatically enhancing its longevity. However, understanding the environment suitable for this type of buildings is the key in selecting a location and justifying the reason for this design. For example, in the town of Coober Pedy in Australia; the ground is so hard that underground homes designed to escape the heat do not need much structural support.

The term "underground" refers to a home constructed entirely below ground, whereas "bermed" describes a home constructed either above or partially below ground, with dirt covering one or more walls (Beqiri, et al., 2018).

Energy storage is an important tool for mitigating the effects of extreme weather on the microclimate within a building and reducing the strain on the building's infrastructure. There is a pressing need for other solutions and a more rational approach to energy usage in buildings due to rising living standards on the one hand and the environmental repercussions of greater exploitation of fossil fuels on the other. When the building is not ventilated, high thermal capacity in a shaded and insulated building can reduce interior maxima by 35-45% of the outside ones. Similarly, the minimum temperature inside will be a few degrees higher than outside. Temperatures inside will rise throughout the day while comfort ventilation is on and fall during the night when it is off. Theoretical predictions about thermal mass's ability to moderate interior temperatures don't always match reality.

An atrium can bring natural light and a sense of spaciousness to an earth-sheltered home, often built underground with a courtyard in the middle. Sunlight and solar heat enter through windows and doors that face the atrium, and the space's below-grade layout keeps the building quiet and out of the wind (Faragalla & Asadi, 2022).

When building a residence with a berm, the exposed side should be oriented toward the sun (south in the northern hemisphere, north in the southern hemisphere) to take advantage of the sun's rays for lighting and heating. Adding skylights to the sheltered home can improve the ventilation and light levels inside. Using the earth as a thermal mass, earth sheltering protects the building from the elements and reduces energy costs. In an earth shelter, the mass of the soil absorbs and stores heat, gradually releasing it to the surrounding area and the nearby home. Because of its great density, Earth experiences a 'thermal lag' where its temperature changes more slowly than the air around it, keeping its surface temperature relatively stable despite the variations in atmospheric temperature. To that end, earth sheltering uses a passive solar building design, which lessens the load on the central heating and air conditioning systems (Foss, 2009). The earthen walls insulate from the chilly winter air and prevent heat from escaping through cracks in the windows and doors. With a focus on the insulating layers and wind speed, the daily temperature inside and outside the Dobraca bermed-earth sheltered home was examined between 2012 and 2016. Even on the coldest winter day in 2012, the temperature inside this bermed-earth covered house ranged from a minimum of 15.8 °C to a maximum of 20.6 °C, which is near the optimal human requirements temperature (Milanović., 2018).

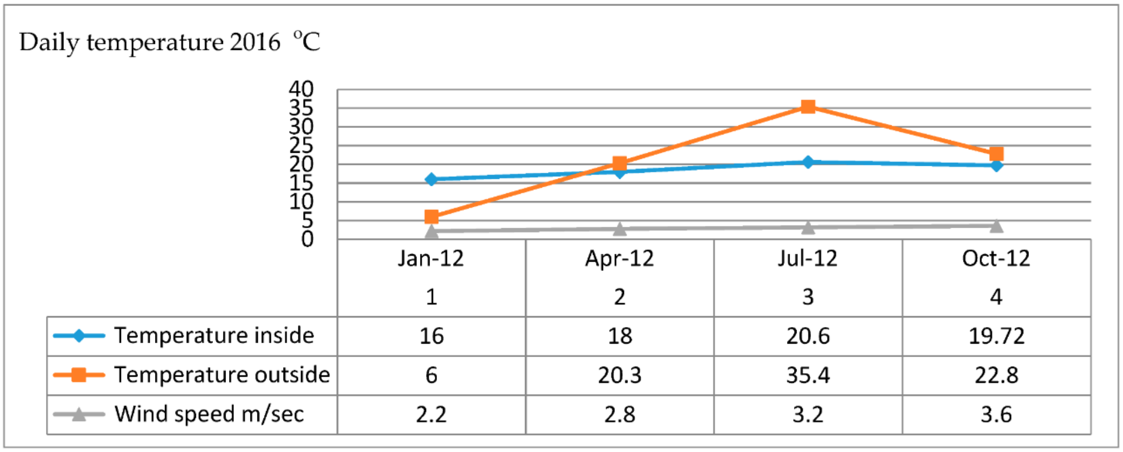

Figure 12 Quarterly measured of daily temperature (14 h) during 2016 in Dobraca bermed-earth sheltered

Aside from being more private and resistant to noise pollution, earth shelters also offer natural soundproofing, which is very useful in busy cities. Underground earth shelters also maximize space utilization, allowing for the cultivation of grass or plants above ground. A low risk of catastrophic destruction means that earth shelters may be cheaper to insure in areas with high winds and frequent natural disasters like hurricanes and tornadoes (Imani & Vale, 2020). The strong earthen walls of earth shelters often lead to restricted air circulation and concerns with indoor air quality, despite many benefits of creating earth-sheltered homes. Air circulation should be considered from the start of the design process; Earth tubes can be utilized to bring in clean air, and exhaust vents can be positioned high up in the structure.

Water seepage is another potential problem with earth-protected housing, so it is important to prepare for it. Earth-protecting structures frequently employ non-biodegradable materials like plastics and energy-intensive concrete, two of the least environmentally sustainable building components, to keep water out. More sustainable goods will need to be incorporated if earth sheltering is used as a green building method in the modern world, and testing is now underway in this field. Climate, soil type, and water table are just a few factors that must be considered before beginning construction on an earth-sheltered building (Khelil & Zemmouri, 2018). Although it requires less finishing and maintenance than traditional construction methods, the initial expenditures can be larger because of the time and effort involved in excavating the site.

Considering all the moving parts, finding a construction firm with sufficient experience in earth-protected buildings might not be easy, but doing so is crucial to ensuring a high-quality result (Imani & Vale, 2020).

Figure 13 Dobraca Bermed Earth-Sheltered House.

Historic earth-sheltering practices show that this type of housing could be a practical alternative in underdeveloped countries, even if its current application uses energy-intensive and non-biodegradable materials. When modern heating and cooling systems are not an option in places with severe temperatures, constructing below ground and taking advantage of the earth's thermal mass may be a cost-effective solution (Khelil & Zemmouri, 2018). As our green spaces continue to shrink, earth sheltering's minimal impact design can help them coexist with their surroundings while providing a sustainable construction technique. However, more study into ecologically friendly structural support is essential to guarantee that the energy used to create homes is kept to a minimum.

To shelter themselves from the desert's extreme heat, species developed smart ways to escape exposure to heat and sunlight. Succulents burying its body underground, the people of Matmata village built their homes beneath the desert ground, and modern-day earth-sheltered structures are all examples of successful strategies to escape the extreme heat. With the correct assessment of the locations, earth-sheltered structures don't have to contribute to CO_2 emissions by using reinforced concrete for stability; humans will learn how to select building materials based on site and material availability to protect themselves from predicted extreme heat by using the earth.

4.1.3.3. **Group 3: Reducing Surface Exposure**

Birds can thrive in various climates because they can regulate their body temperature well. The successful producing metabolic heat is compensated for by ingesting enough energy to match the amount wasted, and mechanisms must be present to release surplus heat as needed. Birds enhance their metabolic rate when the temperature outside drops to keep from experiencing a similar drop in body temperature. However, if the temperature outside becomes too high, birds will need to gather water to cool themselves by evaporation (much as humans do when they sweat). Birds can only release excess heat via their respiratory tract by panting, or in non-passerines, by the fast vibrating of the upper neck and thin floor of the mouth ("gular flutter"). Birds employ several morphological and behavioral features to regulate their rates of heat loss and heat absorption, therefore minimizing the energy cost of maintaining a stable body temperature (the process known as "thermoregulation"). Heat is lost or gained mostly at the body's unfeathered (uninsulated) surfaces. Consequently, when under heat stress, certain birds, including Black Vultures, defecate over their bare legs to promote heat loss by evaporation. (Kurazumi, et al. 2018). This technique in architecture is translated in adaptive facades.

4.1.3.3.1. Desert Animals

1. The Xerus inauris/African ground squirrel

Location: Namibia.

Climate: Subtropical hot and dry.

2. The Jackrabbit/Lepus californicus

Location: south-central and southeastern Texas.

Climate: Subtropical hot and dry.

To protect themselves from the sun's harmful rays, many big animals that must spend most of the day outside turn their bodies in the direction opposite the sun. Protective ground squirrels shield their bodies from the sun by standing erect. The Xerus inauris, an African ground squirrel, will even face the sun and use its tail as a shield while it forages (Figure 10). In the morning, the jackrabbit, Lepus californicus, uses its enormous, highly vascularized ears as a solar collector by holding them out perpendicular to the sun's rays. It does the same thing to stay cool throughout the middle of the day, staying out of the sun and positioning its ears perpendicular to the source of heat to reduce its exposure while maintaining the same radiative surface area.

Figure 14 Desert Animals. African ground squirrel (left), The Jackrabbit (right)

Animals living in the desert may show morphological and anatomical, physiological, or behavioral adaptations. When it comes to animals, desert fur coats are among the first because they are short, hard, and compact while still being well-ventilated, allowing perspiration to escape straight from the skin. To control the amount of heat lost or gained, birds may fluff or condense their feathers. The desert-dwelling ostrich uses radiation and convection cooling thanks to its bare head, neck, legs, and belly, while the bulk of its body is shielded from the sun by its feathers. Small desert animals, like kangaroo rats, are bipedal because it helps them move quickly across broad areas and prevents them from being directly exposed to the ground and its scorching heat. In the desert, bipedal rodents utilize open microhabitats significantly more often than their quadrupedal kin, who prefer to stay in more protected areas.

4.1.3.3.2. Mashrabiyya Design

The Mahsrabiyya is a special element in traditional Islamic architecture that serves as both passive cooling and surface-reducing device on the buildings' facade. The Arabic word for drinking, shariba, is the source of the phrase "mashrabiy'ya," which refers to the window's niche where water jars might be kept for drinking (Kenzari & Elsheshtawy, 2003). Upper-story buildings often include these protruding oriel windows, framed in carved wood latticework and adorned with stained glass. Its primary historical use was as a wind catchment and passive cooling device, as well as an architectural veil for privacy. A clay pitcher with a porous body (whose wall is always wet) is frequently used in these mashrabiyas to chill the fresh air before it reaches the inside of the home. Iranian homes frequently include a water pond underneath the wind catchers, which cools and moistens the air before it enters the inside of the home. Commonly seen on the outside buildings, it may also be seen inside on the sahn (courtyard) side (Abdelsalam, et al., 2013). One of the primary concerns of urban planners and architects has been the creation of environmentally friendly city designs. While many theoretical and applied attempts have been made, most have focused on how sustainability principles may be applied rather than how that can affect the visual character of a city (Abdelsalam, et al., 2013).

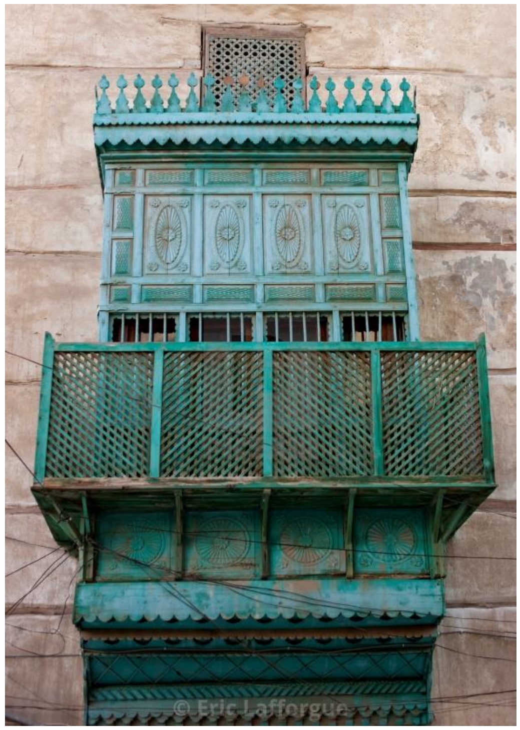

Figure 15 The mashrabiyya.

In particular, during hot seasons, the mashrabiyya functions well as a device to filter out direct sunlight and efficiently lower heat absorption.

There was an experimental study to measure the indoor and outdoor temperatures of Baeshen House in Jeddah, Saudi Arabia. The readings were from two rooms that share the same type of Roshan, except room 1 (1st floor) is an open mesh Roshan, and room 2 (2nd floor) is a closed mesh Roshan. The last measuring station is an outdoor courtyard for outdoor temperature recording. The recorded temperatures were taken in the summer of 2018 from 4th of August to 1st of September. The maximum recorded air temperature in room 1 was 39.3 °C, room 2 was 43.4 °C, and the courtyard was 48.3 °C (Bagasi et al., 2021).

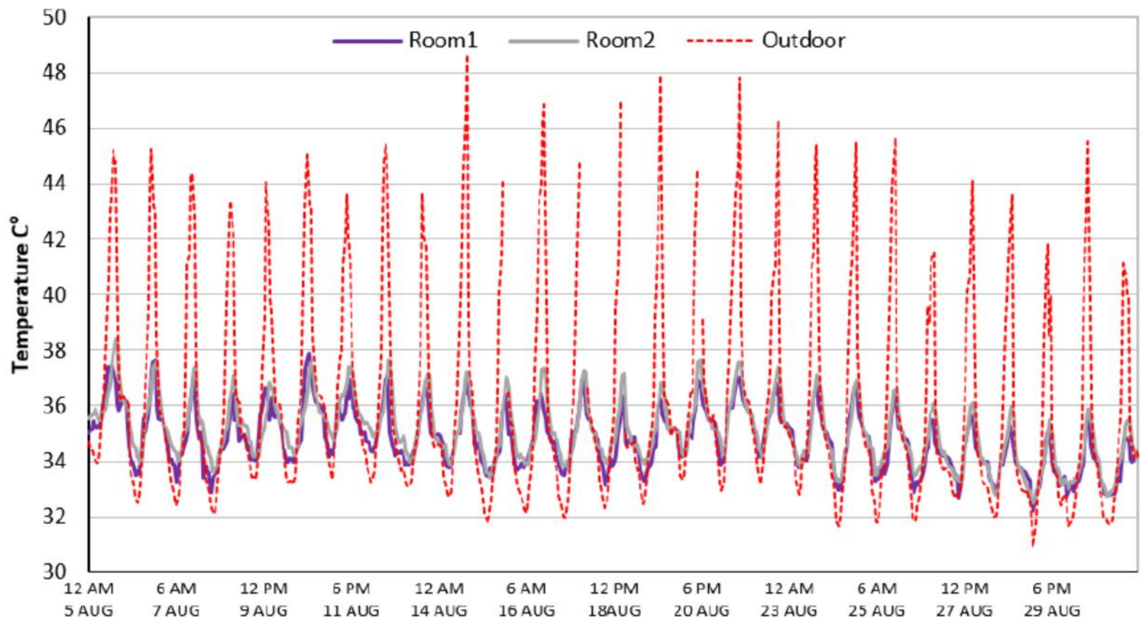

Figure 16 indoor and outdoor air temperature

4.1.3.3.3. Al-Bahar Towers

Location: Abu Dhabi, UAE
Climate zone: Subtropical desert climate.

An abbreviated forecast for Abu Dhabi predicts a week of scorching temperatures, constant sunshine, and zero possibility of precipitation. A tremendous struggle awaits even environmentally conscious builders in such severe climates. Sand may weaken a building's foundation, but the high heat and glare can make occupying indoor spaces difficult. Aedas Architects, commissioned to create the façade for Abu Dhabi's newest pair of skyscrapers, drew inspiration from the "mashrabiya," an Islamic lattice shading mechanism, to create a dynamic and adaptable exterior. The use of air conditioning, which wastes a lot of energy, may be cut by as much as half with the help of a solar screen. To top it all off, the shade's capacity to diffuse light has given architects more freedom in their choice of glass finishes. The screen allows us to employ naturally colored glass, which improves visibility while reducing the need for artificial lighting. It's a fresh spin on an old method that reflects the emirate's desire to be a pioneer in environmental responsibility (Karanouh, et al. (2015).

Al Bahar Towers are designed with an adaptive façade. Unlike static curtain walls, adaptive facades are multi-objective, high-performance envelopes that adjust mechanically or chemically to the dynamics of the outside climate to suit interior load requirements (cooling, heating, lighting, or ventilation) and occupant needs (Attia, 2018).

According to a survey conducted about the towers, when asked about the thermal comfort of the towers, it was reported that 12% of occupants are very comfortable, 42% are comfortable, 32% are neutral, 10% are unpleasant, and 4% are uncomfortable in terms of thermal comfort. Overcooling was the leading reason for discomfort noted by females. Unfortunately, the occupants who participated in the survey reported negative results on the natural lighting section as they were annoyed with the automated façade system and the lack of control and interaction they had with it (Attia, 2018).

Figure 17 Albahar towers

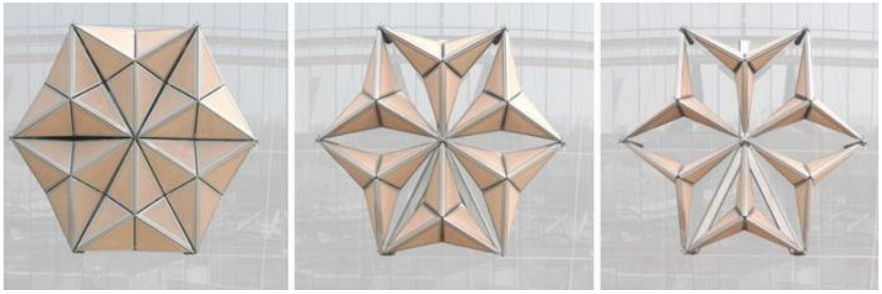

Figure 18 Mashrabiyya mechanism

In the table below, each case study has a temperature reading collected from existing literature. It is clear that the higher the starting temperature of the location, the higher the reduction results so, the reduction number of degrees will not define the success or failure of the strategy. The temperatures in the table are air temperature of the indoor and outdoor as they relate to each project. Except for the desert's succulents, which calculated surface temperature.

Summary of investigated temperatures for the case studies' groups					
Strategy	**Example**	**Location**	**Approx. Outdoor Temp.**	**Approx. Indoor Temp.**	**Reduction**
Passive Cooling	Termite Mounds	Savannas, Africa	31°C	30 °C	1°C
	Windcatchers	Yazd, Iran	40 °C	25 °C	15°C
	Eastgate Center	Harare, Zimbabwe	30°C	24.5 °C	5.5 °C
Escaping Heat	Succulents (living rock)	Deserts	54 - 70 °C	30 °C	24 – 40 °C
	Matmata Village	Tunisia	50 °C	18°C	32°C
	Dobraca House	Kragujevac, Serbia	35.4 °C	20.6 °C	14.8 °C
Reducing Surface Exposure	Desert Animals	NA	NA	NA	NA
	Mashrabiyya	Jeddah, Saudi Arabia	48.3 °C	39.3°C	9 °C
	Al-Bahar Towers	Abu Dhabi, UAE	49.8 °C	HVAC-Controlled	NA

Table 5 Summary of investigated temperatures for the case studies' groups

Note. Sources for temperatures. Termite Mounds: (Gomaa, 2012), Widcatchers: (Roaf, 2005), Eastgate Center: (Smith, 1997), Succulents: (Primrose, 2020)., Matmata Village: (Hassan & Sumiyoshi, 2018), Dobraca House: (Milanović., 2018), Mashrabiyya: (Bagasi et al., 2021).

Table 5 displays the case study groups, strategies, locations, and the difference in air temperature between indoor spaces and outdoor temperatures. A demonstration of the success in reducing outdoor temperature in the interior spaces with the usage of traditional and biomimetic strategies.

4.2. Results

The countries of GCC (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) are the focus of this study as they are described to be “ground zero” for climate change. The countries in question pledged actions to the UN instead of targets in comparison with other countries’ submissions. When looking at the overview of project examples from each country, it is noticed that there is a more commercial and aesthetic priority is given to the projects than sustainable, especially under the current climatic concerns for this group of countries and predicted extreme heat and resource degradation. With an abundant natural resource for heat and natural light, it would have been expected that these countries would use those natural resources on most, if not all new projects.

Traditional architecture of the Middle East has always been the base point from which sustainable successful designs are inspired in this region. The basic classic recommendations that may seem too outdated are the strategies that should be developed using modern technology to create climate responsive architecture that can withstand future extreme weather while protecting people from the expected hot climate.

The urgency in using biomimicry in architectural design is now linked to climate change's direct impacts on the planet. With the help of architecture, humans can produce low-carbon buildings. The groups that were presented in this dissertation urge architects to realize the need that even though extensive research is done on all three areas of knowledge individually, we must look at all three aspects for solutions (extremophiles, vernacular architecture, and modern biomimetic technologies) together. Because relying on only one of these aspects might not yield successful results like Chandigarh City in India, designed by Le Corbusier. Perhaps, for a similar project, if combined with biomimetic technologies that would bring the project closer to its surrounding environment, the project will meet the expected inhabitant rate and can provide interiors that do not threaten the welfare of the people in an increasingly hot region.

Passive cooling, escaping the heat, and reducing surface exposure are only three of the many strategies that can be introduced to buildings in hot regions of the world. When looking at nature to find solutions, we will find plenty of extremophiles that found ways to live and thrive under these circumstances. Not very far from extremophiles, indigenous people utilized their dwellings to adapt to hot temperatures. They have done so by using local materials to produce vernacular architecture that reflects their culture while respecting their surroundings and protecting them from the extreme heat.

The case studies in this research prove that indoor thermal comfort was primarily achieved in the three categories using different approaches. The Eastgate Center and traditional windcatchers have been successful in providing comfortable temperatures without mechanical HVAC systems throughout the year. Matmata underground village and earth-sheltered homes are excellent examples of escaping the heat and maintaining a stable temperature indoors all year round. The mashrabiyya and Al-Bahar towers used similar techniques to protect the indoors by manipulating the facade first with traditional wooden screens and second with kinetic adaptive technology that shaded the glass office towers from uncomfortable glare and overheating during the day.

The features in the case studies can be incorporated into future architectural designs specifically to protect people from dying in extreme heat. The temperature readings from 1997 for Eastgate Center were suitable after one year of inhabiting the center. However, since that time, the climate has changed. Therefore this might no longer be applicable in recent years as temperatures continue to rise and humans' tolerance to heat is 4°C lower than previously thought from 35°C wet-bulb to 31°C. The serious issue to consider by architects while designing for the future is that people's tolerance for heat is now 4°C lower, and the temperatures on earth have increased by 1° Celsius (2° Fahrenheit) since 1880 on average. So, buildings will need to adjust to those changes to avoid reaching the threshold of becoming deserted, like the example of Chandigarh City in India, which is no longer tolerable for humans under the increasing temperatures in India.

Overview of temperatures from the case studies				
Strategy	**Example**	**Approx. Outdoor Temp.**	**Approx. Indoor Temp.**	**Reduction**
Passive Cooling	Termite Mounds	31°C	30 °C	1°C
	Windcatchers	40 °C	25 °C	15°C
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	Matmata Village	50 °C	18°C	32°C
	Dobraca House	35.4 °C	20.6 °C	14.8 °C
Reducing Surface Exposure	Desert Animals	NA	NA	NA
	Mashrabiyya	48.3 °C	39.3°C	9 °C
	Al-Bahar Towers	49.8 °C	HVAC-Controlled	NA

Table 6 Overview of temperatures from the case studies

Note. Sources are the same from Table 5

According to the table 5**,** In the passive cooling strategy section, windcatchers demonstrate the most promising temperature reduction than the other two examples due to the high temperature of Iran's climate as a start. However, both windcatchers and the Eastgate center achieved an acceptable 25 °C and 24.5 °C indoor temperatures which are under the threshold of human tolerance for indoor temperatures. Even though these temperatures fall under the desired limit we are seeking but what remains unknown is whether these strategies can be implemented in the same locations during the current weather extremes but using new technologies. Trans-regional, climate-sensitive technologies, like windcatchers, can inspire us to develop fresh ideas for creating resilient, adaptable, passive structures for hot, warming climates. They can also demonstrate our capacity to live in such structures without air conditioning.

Temperature readings from escaping heat case studies indicate a more extreme reduction in temperature in the desert succulent (living rock) example. However, the human examples of underground homes in Matmata village present a stable 18°C temperature compared to the Dobraca house, where the temperature was 20.6 °C. They both pass as they fall under the human fatal 31°C temperature. Like cave structures, earth-sheltered homes are a sufficient strategy to escape the extreme heat where the location allows. Building underground homes practice is used to reduce energy consumption and use the earth as an insulator with passive ventilation techniques and in modern cases, solar panels. These houses are usually naturally ventilated through small window openings that look to a shared central courtyard. The Dobraca house study reported that the building's interior air temperature shifted less than above-ground brick-based buildings and increased thermal comfort for its occupants.

In reducing surface exposure strategy, the mashrabiyya was able to reduce the indoor temperature by 9 °C. This traditional architectural element, much like the windcatcher, has a disadvantage in modern-day indoor living. The problem with these techniques is that they do not provide enough protection from the outdoor environment. In a home, it is essential to think about ways of keeping both dust and insects out of the interior spaces. This is why the modern interpretation of the mashrabiyya, the popular Al-Bahar towers, should have solved these problems while maintaining the integrity of the local traditional element. However, the two business towers only developed one aspect of the mashrabiyya, which is reducing the surface that is exposed to the sun in Abu Dhabi's hot climate without considering the passive ventilation aspect. The innovative parametric façade design reacts to the sun to prevent uncomfortable glare and overheating for the occupants. However, the entire project is artificially ventilated except for the basement parking levels, which are ventilated through airshafts. According to the results of the survey, some occupants considered the office spaces to be too cold. Which would mean that Al -Bahar Towers failed in using the mashrabiyya as a sustainable technology in modern architecture.

This research demonstrates how regional methods of climate adaptation are essential for creating today's-built environment if we plan to keep designing buildings for climates that cannot tolerate them without electricity. In order to construct buildings for areas with more extreme temperatures in the future, it will be necessary to break away from the monoculture of air conditioning practice. There are two undeniable reasons to demolish such structures right away: building in a world of rising fossil fuel prices and building in a warming environment (Roaf, 2005).

Depending on local building standards, future heat waves will affect structures differently. There is a substantial possibility of increasing energy-related cooling use and power shortages during upcoming heat waves in nations where buildings have air conditioning. Additionally, due to factors including population expansion, economic growth, rising comfort standards, technical advancements, falling buying costs, the UHI effect, the "fear of heatwaves," and climate change, air conditioning may become a norm in nations where it hasn't yet been adopted (Machard, et al, 2020).

The return of investment in this research is not in terms of financial or aesthetic appearance, this research promotes a return on investment in terms of improvement of thermal comfort, protecting people from extreme temperatures. Existing architectural projects focused on return on investment in terms of how quickly these biomimetic interventions pay for themselves in terms of energy. There are also examples of the return on investment that has produced a beautiful aesthetic result, like the mashrabeyya. The return on investment here with the gap this research has identified will only be quantifiable once biomimetic interventions have been demonstrated to successfully reduce temperatures to improve thermal comfort and reduce heat-related illness and mortality without contributing to the conditions that lead to increased temperatures.

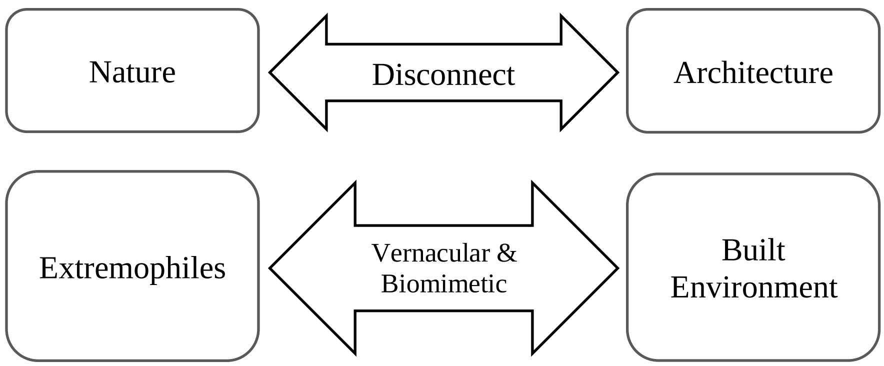

Figure 18 The disconnect between Architecture and Nature

In the table below, table 7, a comparison between the three architectural styles of interest for this research based on energy efficiency and materials use. The results in the table are drawn from the previous examples that are listed from the GCC countries examples. Based on the content of the table, Vernacular and biomimetic architecture styles/approaches are the encouraged choices when considering the state of these locations in the predicted warming future.

Architectural Style Comparison			
	Modern Architecture	Vernacular Architecture	Biomimicry
Energy Efficiency	Can be highly energy efficient with renewable energy technologies or sustainably irresponsible due to the high use of HVAC systems.	Often takes advantage of natural heating and cooling mechanisms, such as passive solar design and natural ventilation, which can help reduce energy consumption and greenhouse gas emissions.	Buildings can be oriented and shaped to maximize passive solar gain, or they can use natural convection to ventilate the space. These strategies can significantly reduce the energy demand of a building, which in turn reduces its carbon footprint.
Material use	Most common materials are steel, glass, plastic, stone, and concrete.	Often uses locally-sourced and sustainable materials, which can help reduce the environmental impacts of the built environment.	Buildings can use recycled or rapidly renewable materials, such as bamboo or straw bale, or they can use low-impact manufacturing processes, such as compressed earth blocks.

Table 7 Architectural style comparison

Note. Source https://www.conserve-energy-future.com/sustainable-construction-materials.php

The reason this research is recommending vernacular and biomimetic design development for future climate, other than it being the solution to find the disconnect between architecture and the natural environment, is because all other types of modifications to protect humans from increasingly extreme temperatures rely on technologies that contribute to the increase of those temperatures, we must look to extremophiles and vernacular traditions of indigenous architecture because those exemplars protect humans (and other species) without contributing to increasingly extreme temperatures. Biomimetic options and indigenous vernacular traditions have substantially lower lifecycle embodied carbon and lifecycle embodied energy profiles as compared to architecture that relies on mechanical HVAC systems (regardless of how energy efficient those mechanical HVAC systems may be). Keeping in mind that ten percent of the power consumed worldwide comes from fans and air conditioners. Demand is anticipated to triple or quadruple by 2050; one prediction predicts that 700 million new AC units would be installed globally by 2030 (Wells, 2019).

CHAPTER V: CONCLUSION AND FUTURE WORK

5.1.Conclusion

The sampling, evaluation, and combination of biomimetic principles, vernacular architecture, and case studies in this dissertation indicate the qualitative-interpretative synthetic approach to designing the architecture for humans living in the GCC region without exacerbating those extreme conditions. If they could apply these strategies that combine natural, vernacular and biomimetic technologies to the future built environment, humans would live in extreme weather conditions without fear. Climatic factors play a significant role in the choice of living for individuals. However, with proper architectural designs, homes in extreme temperatures will be regulated to average temperatures and use natural methods. The need for biomimetic principles and vernacular architecture will reduce the use of artificial and excessive mechanisms.

Humans are less tolerant to excessive heat and humidity than previously thought, from 35°C wet-bulb to 31°C wet-bulb, which is raising the mortality rate in countries like the GCC countries where heat is causing construction workers to die from heat stroke.

Termite mounds and Ariocarpus fissuratus are a few living organisms that use natural solutions to provide ventilation for themselves. Given their unique methods of creating cool temperatures in regions that observe incredibly high temperatures. Mick Pearce's Eastgate center and Matmata underground villages utilized the ideology of the organisms and were able to record high success rates in achieving and maintaining thermal comfort. Great outcomes for the built environment and the planet will be guaranteed if future designers learned from these organisms despite their inferiority to human power. Underground buildings are being created and are known to have a unique cooling effect that doesn't require additional ventilation (Primrose,2020).

According to recent research, 40% of carbon (IV) oxide emissions result from energy waste from significant buildings (Primrose,2020). Such numbers account for the increase in temperatures and, consequently, global warming. The dangers of climatic changes are inevitable if humans continue to avoid precautionary measures. Humans are destroying their only opportunity to survive by using resources that are only advantageous now.

The world can be improved, and a better place is created if only people take the chance and use traditional ways and natural styles in their modern designs. When Mick Pearce invented the Eastgate design, it was recognized as a building that required no artificial methods for handling temperatures. It was expected that more architects would emulate the designs but not so many people followed the example.

The next thirty years will be rough on human beings if drastic measures are not taken. Once the climate has been affected, unlike human-made disasters, it will be impossible to revert the changes. Climates take years before they change. Therefore, human life will be threatened by a harsh climate due to global warming. Many lives will be lost due to climatic changes as the human body is built to sustain environmental conditions.

There’s an increasing sense of urgency that architects must draw on all resources to figure out how to protect humans. Nature, vernacular architecture, and biomimetic strategies are the three areas identified in this research where architects can draw upon and synthesize a new approach to architectural design to protect human life. Because it is the architect's duty to prioritize people's health, safety, and welfare. If the inhabitants die from heatstroke, all those principles disappear. Therefore, the need is urgent—it cannot be overstated—and what people have attempted in the past by concentrating only on one of the three areas of study needs to change because deaths are still occurring, and temperatures will keep rising. Especially in a hot-spot region like the gulf region where all the GCC countries are located.

One of the best examples for implementing the principles of sustainable design is vernacular architecture. It produced excellent symmetry and a perfect balance between form and function. The components of vernacular architecture were designed to coexist, enhancing one another's strengths and complementing various climatic, environmental, and socioeconomic circumstances. The concepts of vernacular architecture must be reexamined in modern architecture, together with the criteria of sustainable development, and these ideas must be combined with contemporary technologies. To sum up, traditional architecture may be utilized with current technology (biomimicry) to build a more sustainable planet that can withstand change.

5.2.Future Work

The most critical area requiring effort to advance a sustainability agenda based on nature's principles is a shift in mindset. This research encourages concepts like expanding the number of non-human species, the number of groups living in extreme conditions, the number of case studies; and incorporating more data (life-cycle embodied energy and CO_2, post-occupancy thermal comfort, worker performance, impacts of biomimetic and passive climate features on computers and other equipment, structural resiliency, etc.) to balance the qualitative with the quantitative so that humans can develop strategies for designing and creating indoor environments that incorporate the extreme exterior environments. Cases such as the Eastgate center should be observed in the current world. With threats of climatic changes, architects need to reconsider developing weather-conditioned designs in that the houses can handle extreme weather conditions independently. Innovative technology will also help control the thermal conditions of new human habitats.

More research needs to be conducted on how humans can utilize every natural resource to survive extremely hot temperatures. During summer, most individuals fly to other countries with more sustainable temperatures for vacation because they cannot handle the summer heat. However, this shouldn't be the case. Architects and designers, together with scientists, need to develop ways such temperatures can be used to develop essential livelihood needs. The energy released in extreme temperatures can be channeled to create something more resourceful such as renewable energies.

Future researchers can also consider practical biomimetic approaches. Mick Pearce's Eastgate case study has been overused in many biomimetic approaches, and it's time for more recent developments to be designed and built with recent climatic studies in mind.

Through simulations and the use of Artificial Intelligence, future researchers can create a virtual environment that will be used to test the workability and functionality of the recommendations from biomimetic research (Turner,2008). Architects have an opportunity to use these technologies to determine the success rates of using biomimetic designs on larger scales. Investors and governments are likely to invest resources on opportunities whose results they can see. The recent efforts put in designing habitats for other planets are fertile resources for these projects to be implemented on earth if need be. If humans treated habitat on earth the same way they expect habitat on Mars to be, they would only be able to use local materials to create buildings as they would be limited to how much materials they can bring from the earth.

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